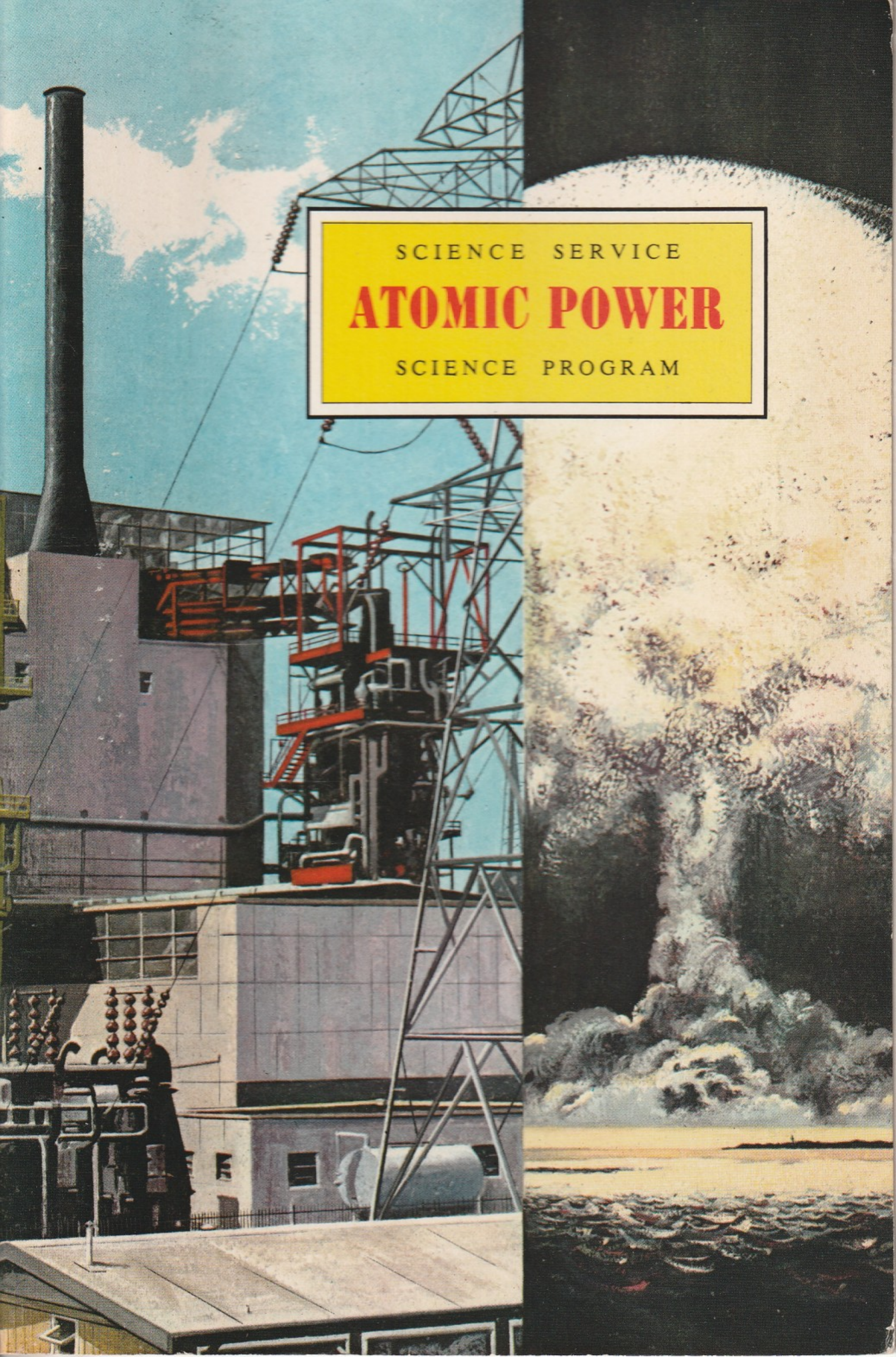
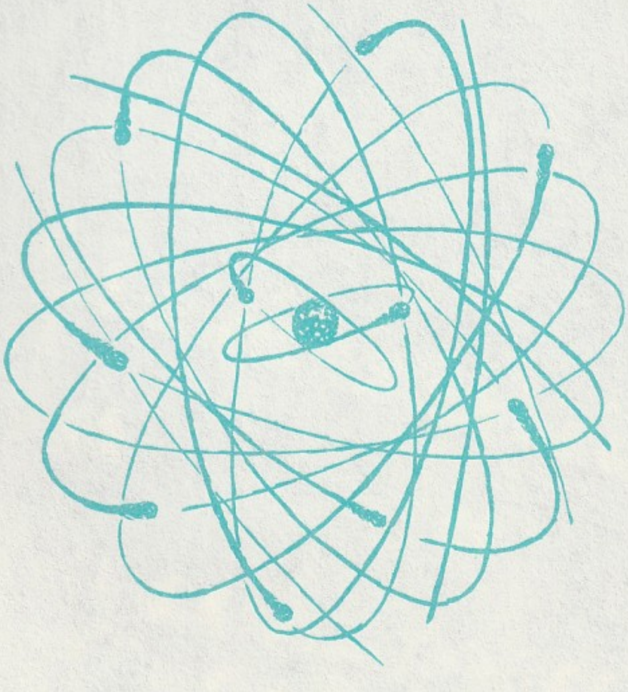


SCIENCE SERVICE

ATOMIC POWER

SCIENCE PROGRAM

ATOMIC POWER



SCIENCE PROGRAM

Prepared with the co-operation of
Science Service

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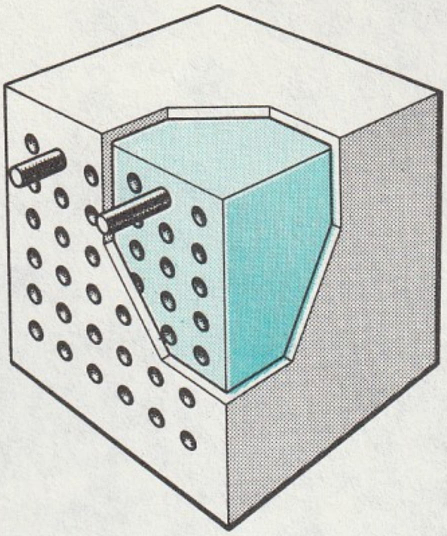
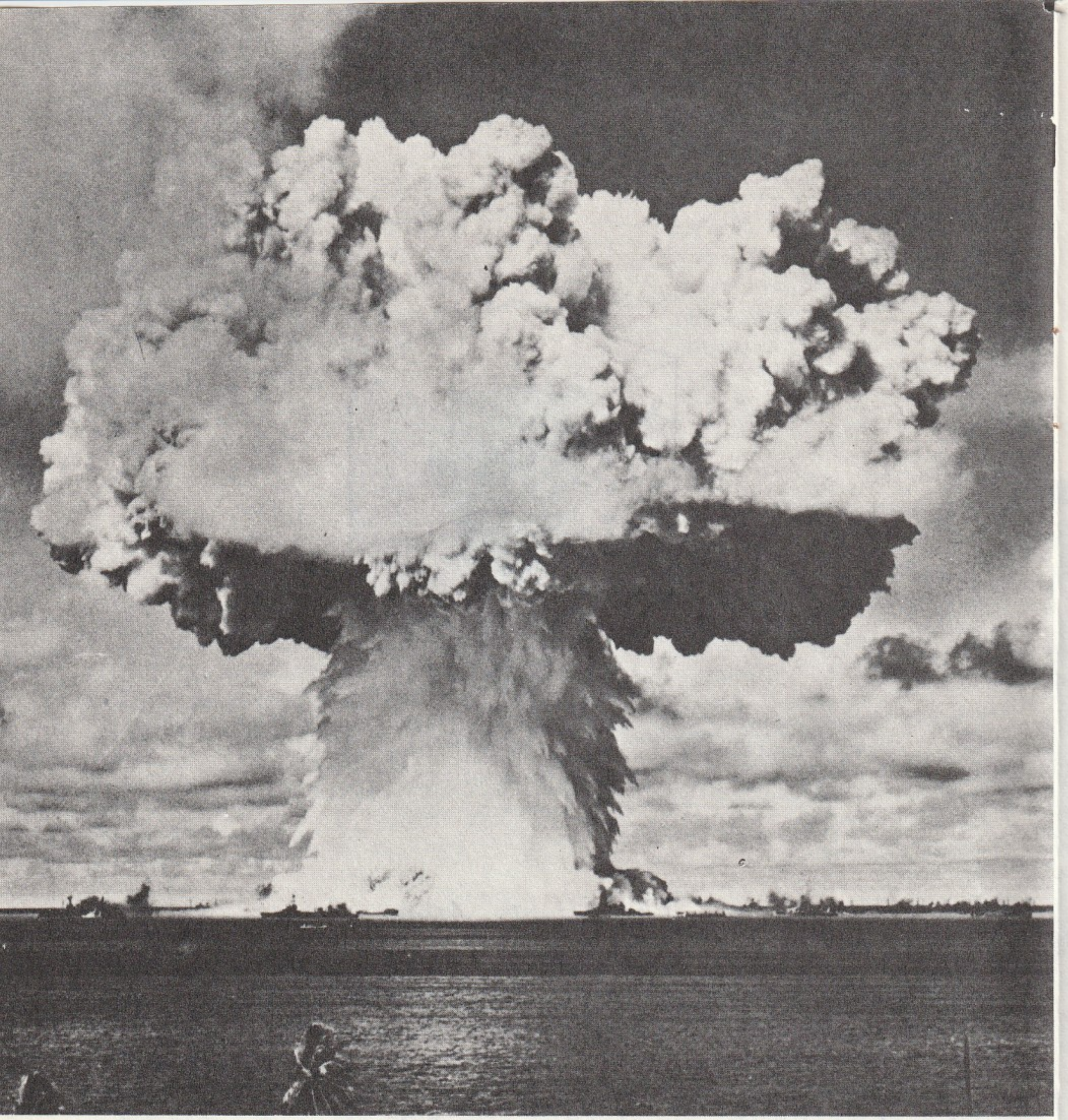


The Mighty Atom

MAN'S GREATEST POWER SOURCE is the energy locked within the atom, the building block of nature from which all things are made. On 6 August, 1945, the destructive forces of atomic energy—and man's fury—were unleashed in the skies over the Japanese city of Hiroshima. But Hiroshima was neither the beginning, nor atomic bombs the end, of the story of the atom. Its power has been controlled and put to work, not for devastation, but for the generation of electric power and the propulsion of ships, and in medicine, agriculture and industry. The atom is helping to fight and cure disease, to increase the world's food supply and to help explore space.

In ancient times, it was commonly believed that all physical things were made of materials which man knew and understood. People thought that by combining fire, water, earth and air in the proper proportions and under the right circumstances, it should be possible to duplicate any material thing.

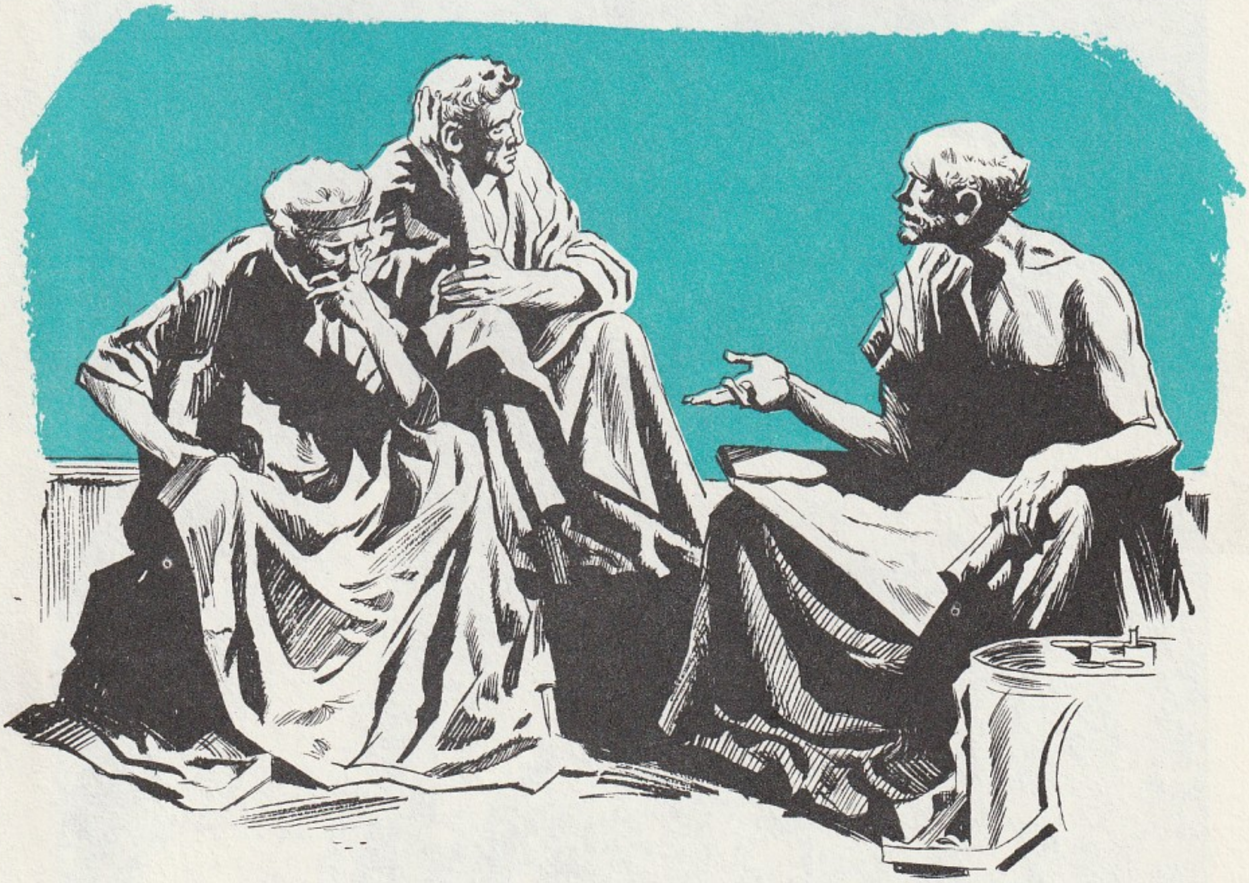


At Bikini Atoll—atomic devastation.

The Greek philosopher Leucippus, who lived about five hundred years before Christ, disputed this belief. He said that all things were made from some kind of small, indivisible particles. Since the Greek word for indivisible was *atomos,* the word "atom" came into being. His pupil

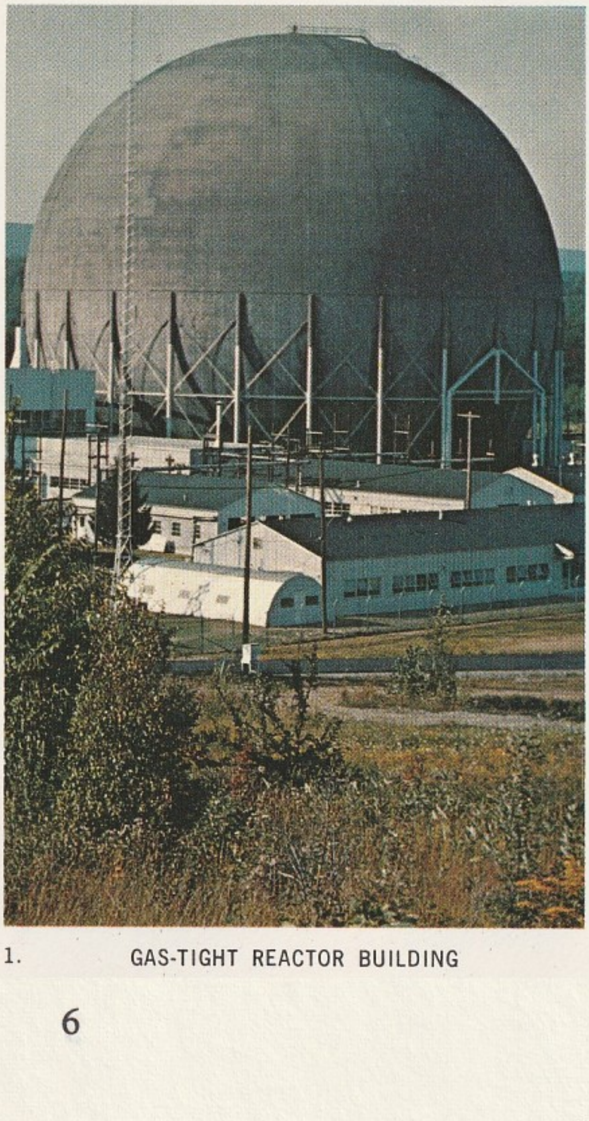
Democritus elaborated on this theory. He insisted that the atom could not be taken apart or made smaller and that it entirely filled the space it occupied. He thought that all atoms were essentially the same but that those of a liquid were smooth, round and slippery, whereas those of a solid were rough and jagged. Hence, a liquid could flow and a solid could not.

Leucippus and other ancients believed that since all atoms were alike, it was the pattern in which they were combined that made one substance different from another. Although incorrect, this theory did lead to other ideas. If everything is made from the same set of building blocks, it was conjectured, why would it not be possible to disassemble the blocks of a common, inexpensive substance and rearrange and rebuild them to make gold or some other valuable material? This goal was fascinating and many men spent their lives vainly in its pursuit. Thus was born the alchemist's art, and from it grew the science of chemistry.



Democritus elaborating on the atomic theory.

Through chemistry, the nature of things was more clearly revealed. The chemist broke down compounds into elements. He identified these elements, numbered them, weighed them and studied them. He discovered and worked with the molecule—that collection of atoms in a substance which is bound together and acts as a unit. He conducted experiments aimed at determining the nature of the atom and its physical size. In the year 1803 John Dalton, an English chemist, broke with an historic Greek concept and concluded that the atoms of different substances must have different sizes and weights. His book, *A New System of Chemical Philosophy,* published in 1808 with its presentation of atomic theory and a table of atomic weights, represented an important development in chemistry.



Just as towering smokestacks signify conventional power stations, these giant gas-tight buildings signify a certain type of atomic power station. This one was built near Schenectady, New York.

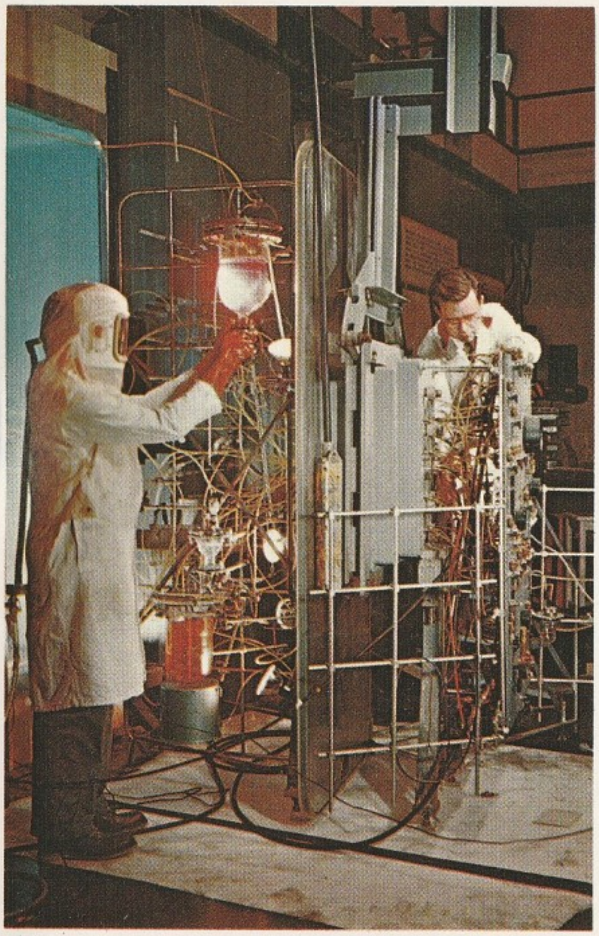
1. GAS-TIGHT REACTOR BUILDING

HENRI BECQUEREL

BECQUEREL AND RUTHERFORD

Radioactivity—a Puzzle

CLOSE TO THE END of the nineteenth century there began another series of events that led to our present understanding of this extremely small something called the atom. In 1896 a distinguished French scientist and university professor, Antoine Henri Becquerel, announced the discovery of the process called *radioactivity*. While experimenting with uranium salts, he found that it emitted invisible rays of considerable power.

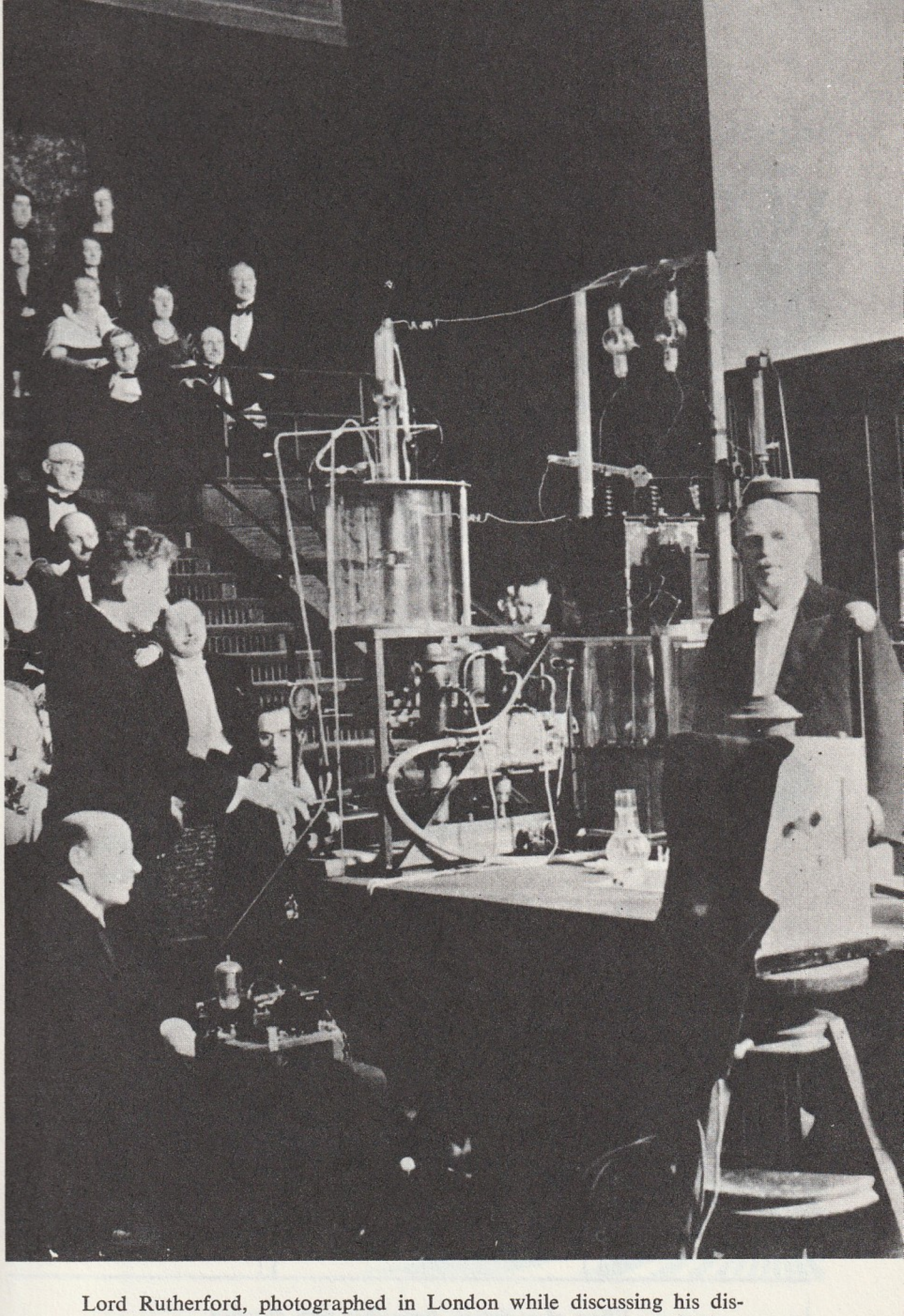


2. PREPARING A HOT CELL

Hot-cell apparatus is being prepared here for an experiment involving highly radioactive material at Brookhaven National Laboratory in Upton, New York. Since the cell was contaminated by previous experiments, the technician in direct contact, at left, has to wear protective clothing.

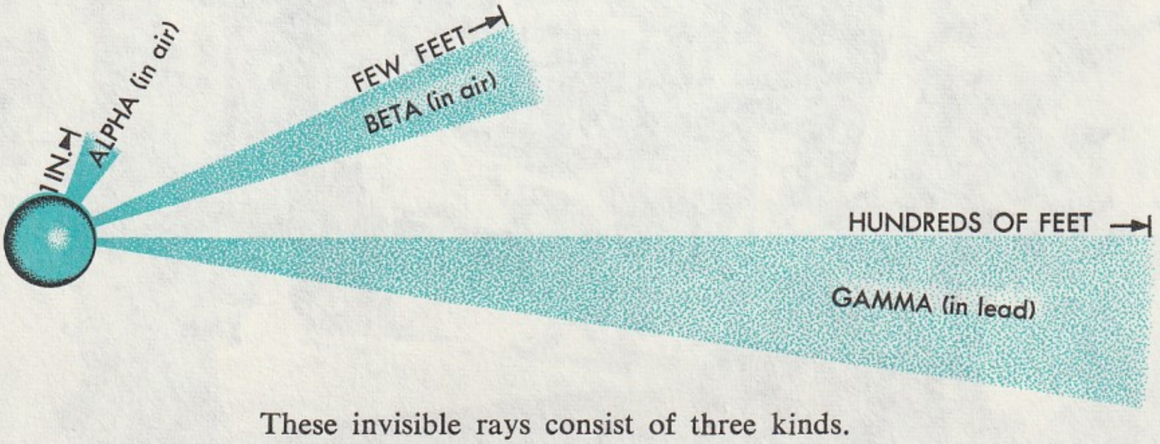
He placed his uranium sample on an unexposed photographic plate. Some time later, when the negative was developed, Becquerel found that he had a photograph made by these rays, and their paths showed on the plate.

Becquerel's discovery was indeed astounding. What were these rays? What caused them? Ernest Rutherford, later Lord Rutherford, a British physicist, undertook to find out. In 1899, using Becquerel's photographic technique but substituting radium for uranium, he placed a sample in direct contact with film, developed it and observed the recorded radiation pattern. Next he placed a piece of paper between the radium and the film and repeated the process. Finally he placed thin sheets of metal foil between the two and again repeated the process. He noticed that when there was no barrier between the film and the radium, the photograph revealed a more complex radiation pattern than it did in the photo with the paper inserted between the two. He concluded that one type of

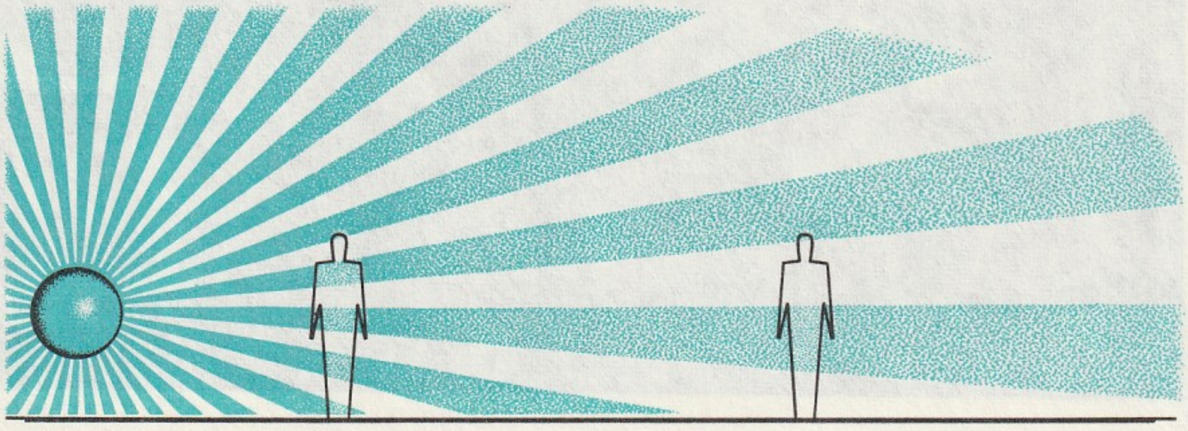


Lord Rutherford, photographed in London while discussing his discoveries before a distinguished audience at the Royal Institution.

Radiation from radioactive material cannot be seen, heard, smelled, tasted, felt.



These invisible rays consist of three kinds.



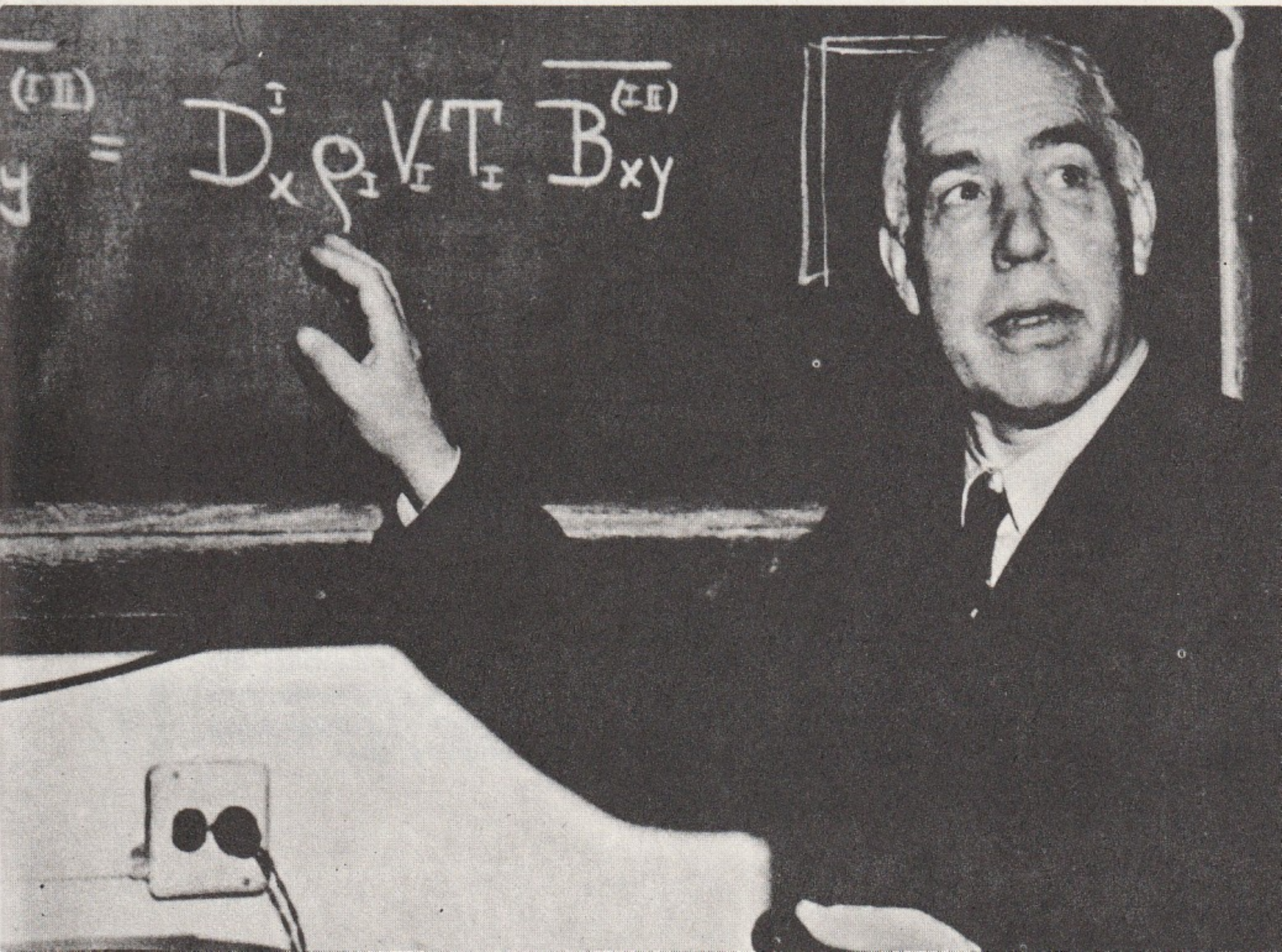
Effect of radiation diminishes with distance.

radiation was stopped by the paper. He called this type *alpha radiation.* A similar comparison with the other photos showed there was still another type of radiation that passed through paper but not through foil. This he called *beta radiation.* Finally he noticed that there were rays that passed through the foil no matter how many thicknesses he used. A short time later another scientist, P. Villard, succeeded in stopping this radiation by making a barrier of iron and lead several inches thick. This was called *gamma radiation.*

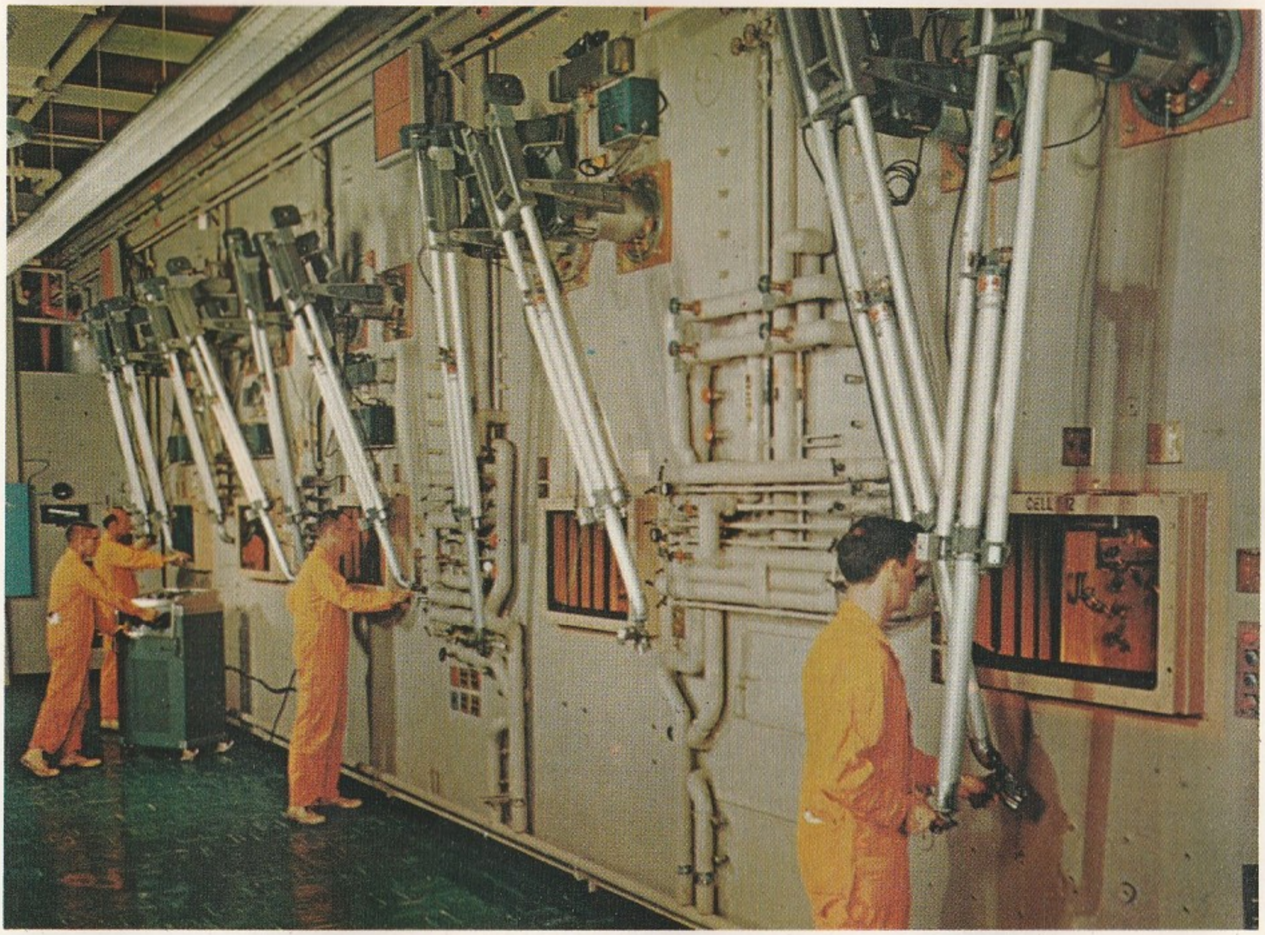
The Atom Takes Shape

While Becquerel and Rutherford had been trying to solve the riddle of radiation, another famous British physicist, Sir Joseph Thomson, announced in 1897 a discovery that was equally important. An authority on electricity and its behavior, Sir Joseph had discovered the existence of an extremely small electrically charged particle.

Niels Bohr



While experimenting with the rays produced in a cathode tube, he tried to change the path of these rays by subjecting them to strong magnetic forces. It is interesting to note that, at the time, scientists could not agree if these rays were waves such as light, or streams of extremely small particles. Thomson's experiments proved that they acted like particles and, in fact, weighed 1/1840 as much as a hydrogen atom. There could be little doubt that these particles, later called *electrons,* were constituents of all atoms even though no one could exactly determine their size or shape.



3. CONDUCTING HOT-CELL EXPERIMENTS BY REMOTE CONTROL

In perfect safety from harmful radioactivity, these technicians are conducting experiments inside individual hot cells by remote control. The cell windows are made of many layers of special glass, resistant to radiation which would darken ordinary glass.

GLOSSARY of NUCLEAR TERMS

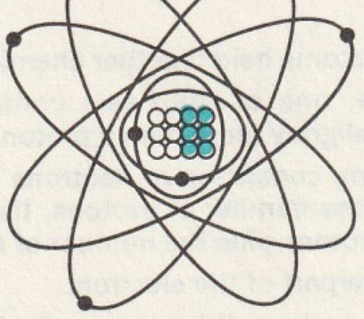
ALPHA RAY	Energetic but non-penetrating radiation emitted by heavy radioactive nuclei.
ATOM	A positively-charged nucleus surrounded by negatively-charged electrons.
ATOMIC ENERGY	Energy released in nuclear reactions, such as in fission.
ATOMIC REACTOR	A machine for maintaining a controlled chain reaction.
BETA RAY	An energetic electron or positron emitted by some radioactive nuclei.
CHAIN REACTION	Self-sustained sequence of fissions.
CONTROL ROD	A rod of neutron-absorbing material used to control the power level of an atomic reactor.
CRITICAL MASS	The amount of fissionable material needed to sustain a steady chain reaction.
CYCLOTRON	A machine that accelerates charged particles to high energy.
ELECTRON	A particle having a unit negative charge and a weight equal to 1/1840 of the weight of the lightest atom (hydrogen).
FISSION	The breaking-up of a heavy nucleus into two or more fragments. A large amount of energy and some free neutrons are released in the process.
FUSION	The combining of light nuclei into heavier ones with a release of energy.
GAMMA RAY	Energetic, penetrating electro-magnetic radiation emitted by certain radioactive nuclei.
ISOTOPES	Atoms whose nuclei have the same number of protons but a different number of neutrons.
MESON	A particle intermediate in weight between the electron and the proton.
MODERATOR	A material used in atomic reactors to reduce the speed of neutrons.
MOLECULE	A combination of atoms held together chemically.
NEUTRON	A neutral particle, one of the basic constituents of the nucleus, weighing slightly more than a proton.
NUCLEUS	The core of an atom, consisting of neutrons and protons. Its charge is equal to the number of protons. Its weight is equal to the number of protons plus the number of neutrons.
POSITRON	The positive counterpart of the electron.
PROTON	A constituent of the nucleus. It has one unit of positive charge and weighs slightly less than a neutron.
RADIATION	Energetic charged particles, neutrons and gamma rays which cause ionization in matter.
RADIOACTIVITY	Spontaneous nuclear decay, releasing an alpha, beta or gamma ray.

The Nucleus

In 1911, Rutherford proposed, and Niels Bohr, a Danish scientist, developed the nuclear model of the atom wherein it was likened to the sun and planets of our solar system. It was a convenient, understandable and, for a time, workable idea. Lord Rutherford imagined the atom as consisting of a central, positively charged core or *nucleus,* around which tiny, negatively charged electrons revolved in orbits. The nucleus was described as being responsible for practically the entire atomic mass and as having one or more heavy particles within its structure. The number of particles in the nucleus determined the kind of atom it was. The orbiting electrons, extremely small, and at a considerable distance from the nucleus, were equal to the number of particles in the nucleus but opposite in electrical charge.

Bohr reasoned that the attraction of the positive charge in the nucleus for the negative charge on the electrons was balanced by the inertia that the electrons have because of the forward movement in their orbit. This keeps the electrons moving in their orbit. It was later visualized that, unlike the solar system, more than one electron could occupy the same orbit, later called a shell and now, more properly, a cloud.

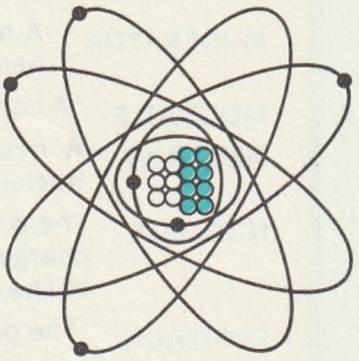
ISOTOPES OF CARBON



CARBON 12

Naturally-occurring

Protons	6
Neutrons	6
Mass	12

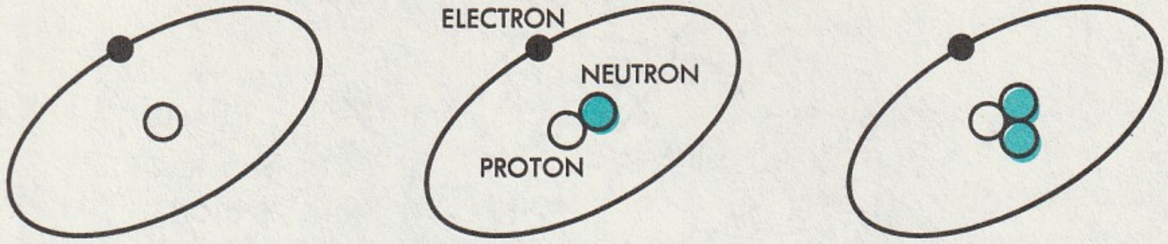


CARBON 14

Man-made

Protons	6
Neutrons	8
Mass	14

ISOTOPES OF HYDROGEN



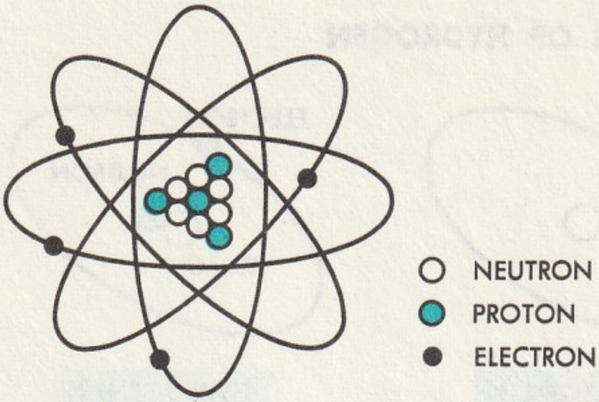
HYDROGEN 1 called PROTIUM	HYDROGEN 2 called DEUTERIUM	HYDROGEN 3 called TRITIUM
Naturally-occurring	Naturally-occurring	Man-made
1 proton	1 proton	1 proton
1 electron	1 electron	1 electron
0 neutrons	1 neutron	2 neutrons

Isotopes

According to this theory, one atom of any substance should have precisely the same number of nuclear particles and the same number of electrons as any other atom of that same substance, and for some elements this is true—but for some it is not. Uranium, for example, was found to exist in several varieties, each with a different weight. Where more than one kind of element existed, as in uranium, each kind was called an *isotope*. Although each variety seemed to check out with the accepted theory of charged nuclear particles and electrons, each variety of uranium, chemically the same, had a different *atomic weight*. Since the electron was so small as to be almost weightless, whatever accounted for this difference had to be in the makeup of the nucleus of the atom.

The Proton and the Atom Smasher

Electricity had long since become a tool of the physicist and was used to explore the realm of the atom. Even Becquerel's rays and Thomson's electrons had been put to work, and by 1903 Rutherford had predicted that alpha rays were from the nucleus of a helium atom and that beta rays were high-speed electrons. Gamma rays were later found to be extremely powerful short-wave radiations similar to X rays, except



THE ATOM

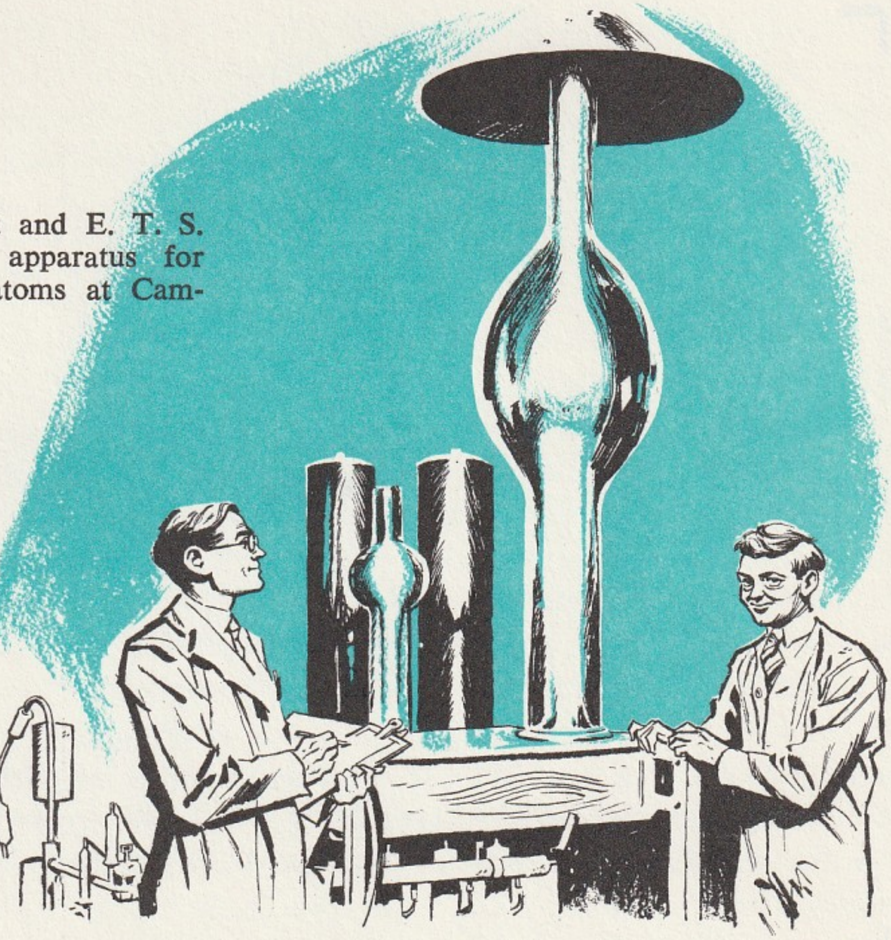
that gamma rays come from the atomic nucleus, while X rays come from electrons in the shells surrounding the nucleus.

Since subatomic particles are electrically charged, their behavior should change in different magnetic and electric fields and experiments were conducted to explore such effects. By bombarding gaseous elements with alpha particles, Lord Rutherford found that the collision always produced a positively charged hydrogen nucleus. Thus in 1919 he proved by experiment the existence of the first particle of the atomic nucleus—the *proton.* Here then was confirmation of the nuclear theory. As predicted by Rutherford and Bohr, this particle did have a charge equal to, but opposite, the negative charge of the electron. Equally important, Rutherford accomplished the age-old dream of the alchemists. He converted, or transmuted, atoms of nitrogen into atoms of oxygen. Here was the beginning of a new era when atom smashers would be used. By 1932 particle accelerators were built which shot protons as bullets to break up atoms.

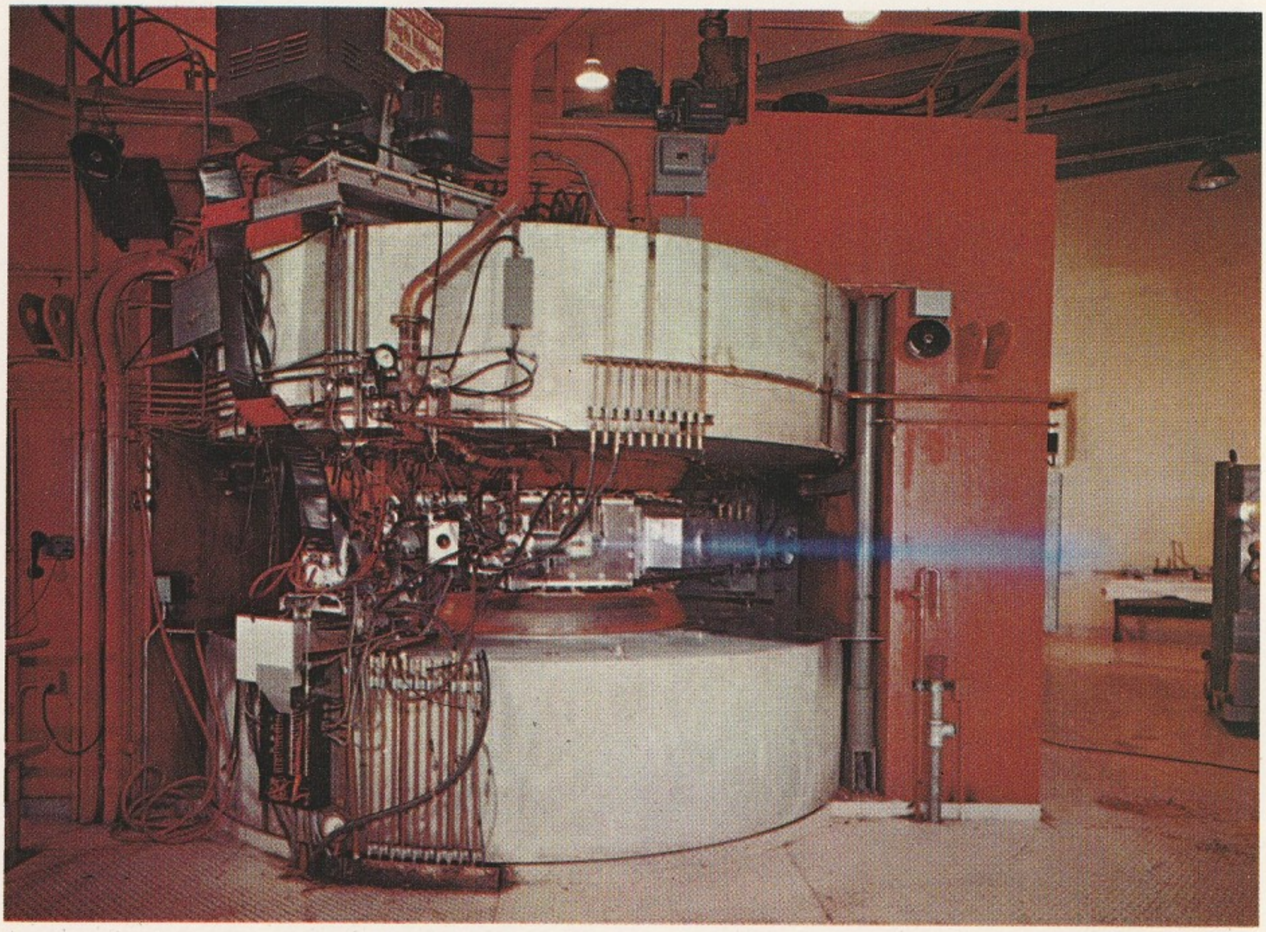
Neutrons and Atomic Weight

IN 1932, SIR JAMES CHADWICK discovered another particle of the atom's nucleus. It was about the size of the proton but with no electrical charge. Hence it was called the *neutron.* It was now possible to see why there were several kinds of uranium. Some varieties contained more neutrons in their nucleus than did others. The extra neutrons changed atomic weight. Atomic weight is roughly the total number of protons and neutrons in an atomic nucleus. The scale is an arbitrary one in which oxygen, with eight protons and eight neutrons, has been assigned the number 16.

Sir John Cockcroft and E. T. S. Walton with the apparatus for smashing lithium atoms at Cambridge in 1932.



Professor James Chadwick holds the 1935 Nobel prize in physics while talking to King Gustav of Sweden, who has just made the presentation. Three years earlier, Chadwick had discovered the neutron while working at the Cavendish Laboratory of Cambridge University in England.



4. A 21.6-MILLION-ELECTRON-VOLTS BEAM OF DEUTERONS

The cyclotron at the Argonne National Laboratory, near Chicago, Illinois, was built to study nuclear reactions and also to produce radioisotopes. The blue beam of deuterons is travelling at a speed of 28,000 miles per second!

It was Sir John Cockcroft and E. T. S. Walton who first used an atom smasher to disintegrate lithium atoms, with high-speed protons as bullets.

By 1933 it was known that the atomic nucleus contained protons and neutrons around which electrons orbited in concentric orbits called shells. Protons and neutrons are heavy and each weighs more than eighteen hundred times as much as an electron. Since there are about 100 billion billion atoms in the head of a pin, to say that an atom is small is a vast understatement. Numbers of this size are almost beyond comprehension. For instance, assume for a minute that you could see the atoms in the pin head and started counting them at the time of the creation of the earth, which is estimated to be approximately six billion years ago. If you counted those atoms at the rate of one per second continuously day and night since creation, as of now you would have counted only approximately 1/100 of all the atoms contained in the pin head.

Small as the entire atom is, its diameter is thousands of times greater than the diameter of its nucleus. The atom—in terms of volume—is mostly empty space.

The "Glue" of the Nucleus

SINCE UNLIKE ELECTRIC CHARGES (positive-negative) attract each other, and since like charges (positive-positive or negative-negative) repel each other, the nuclear concept of the atom provided still another puzzle. If the closely packed, dense nucleus consists of groups of positively charged protons and uncharged neutrons, what holds the nucleus together? Since protons contain like charges, do they not fly apart? The obvious answer is that the atomic nucleus must be held together by another powerful force, a kind of nuclear "glue", strong enough to overpower the natural tendency of the protons to repel each other. This energy is called the *binding energy* of the nucleus, and is the strongest force yet discovered

Radioactive materials for scientific study are safely transported from reactor to laboratory in shielded casks, like the one shown suspended from its overhead crane. A research worker checks the "hot" cask with a portable Geiger counter.

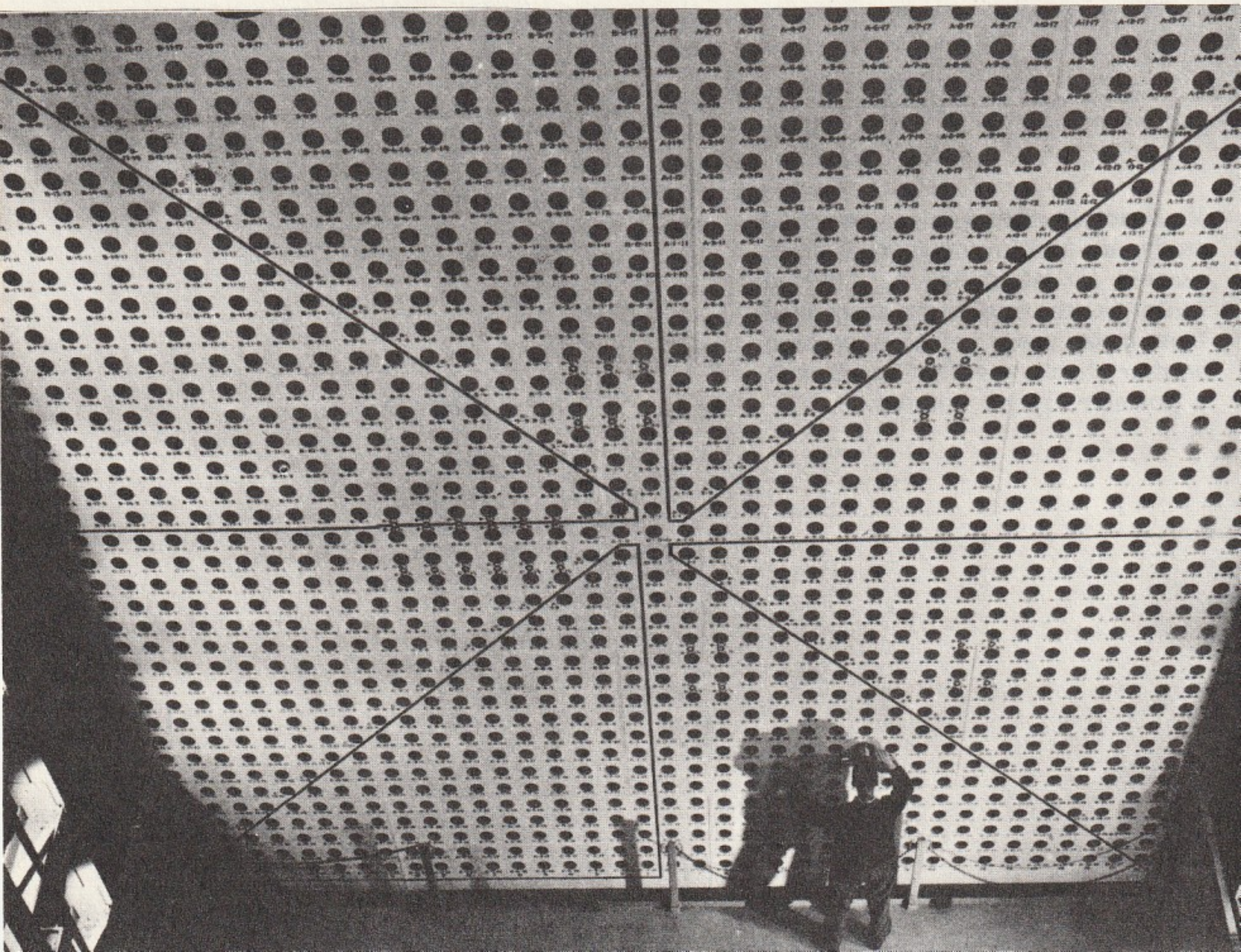
5. CHECKING A "HOT" CASK

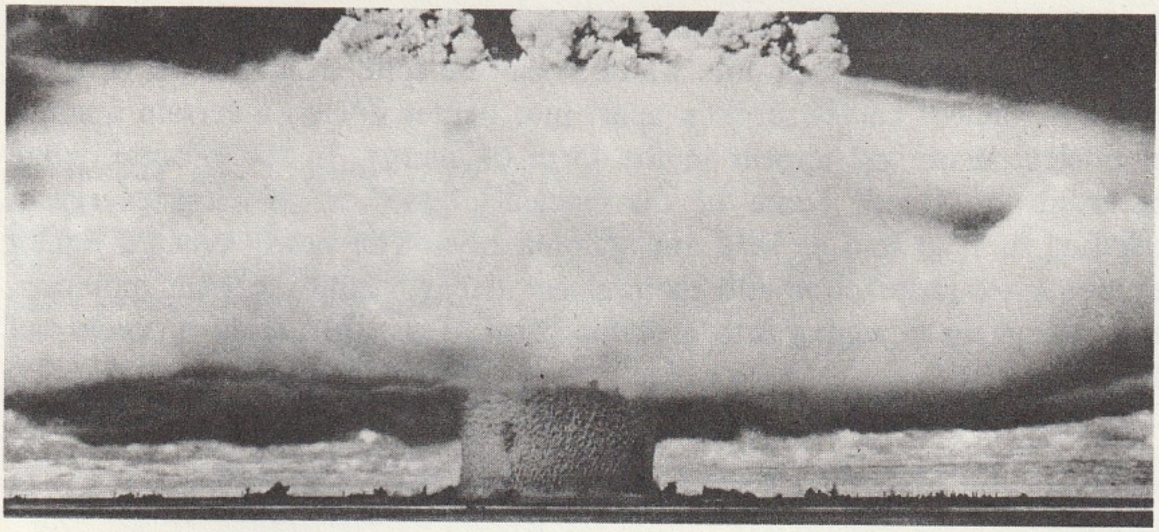
by man. It is a force about which little is known. It is the mystery behind the power of the atom.

To illustrate a little more clearly the properties of binding energy, let us conduct an imaginary experiment. We know that a helium atom contains two protons and two neutrons in its nucleus. If we were to try to assemble our own helium nucleus from a stockpile of protons and neutrons, we would soon discover that matter and energy are actually the same thing, but in different form. If we took two protons from our stockpile, they would each have a mass of 1.0076. If we then took two neutrons from our other stockpile, we would find that they each have a mass or weight of 1.0090.

These rather odd numbers result from the original assignment of atomic weight 16 to oxygen, at a time when isotopes were unknown. Actually most elements have several isotopes of differing neutron content and therefore the atomic weights are an average weight of their isotopes.

The south face of the Brookhaven reactor is a wall five feet thick. Pure uranium is loaded into the reactor through numbered holes. The technician is using a periscope to view the handling of radioactive materials by remote control. The reactor was placed on stand-by status in 1968, after eighteen years of continuous operation.





We should imagine, then, that when our "helium factory" assembled these cosmic building blocks into a compact helium nucleus, its mass would be equal to the sum of its parts. According to the masses listed above, our helium atom should have a mass of $2(1.0076)+2(1.0090)=4.0332$. But it does not. Instead, the helium nucleus has a mass of 4.0028. What has happened is that in making a helium nucleus out of our building blocks, 0.0304 units of weight have become excess material.

This matter disappears because it is converted into energy. On the other hand, to take the nucleus apart we must use an amount of energy equivalent to the matter which disappeared when we put the nucleus together. This additional energy is what acts to hold the nucleus together. Thus the heat of the sun is due to the constant *fusion* of hydrogen nuclei into helium nuclei. The tremendous power of the hydrogen bomb depends upon this reaction.

Fusion and Fission

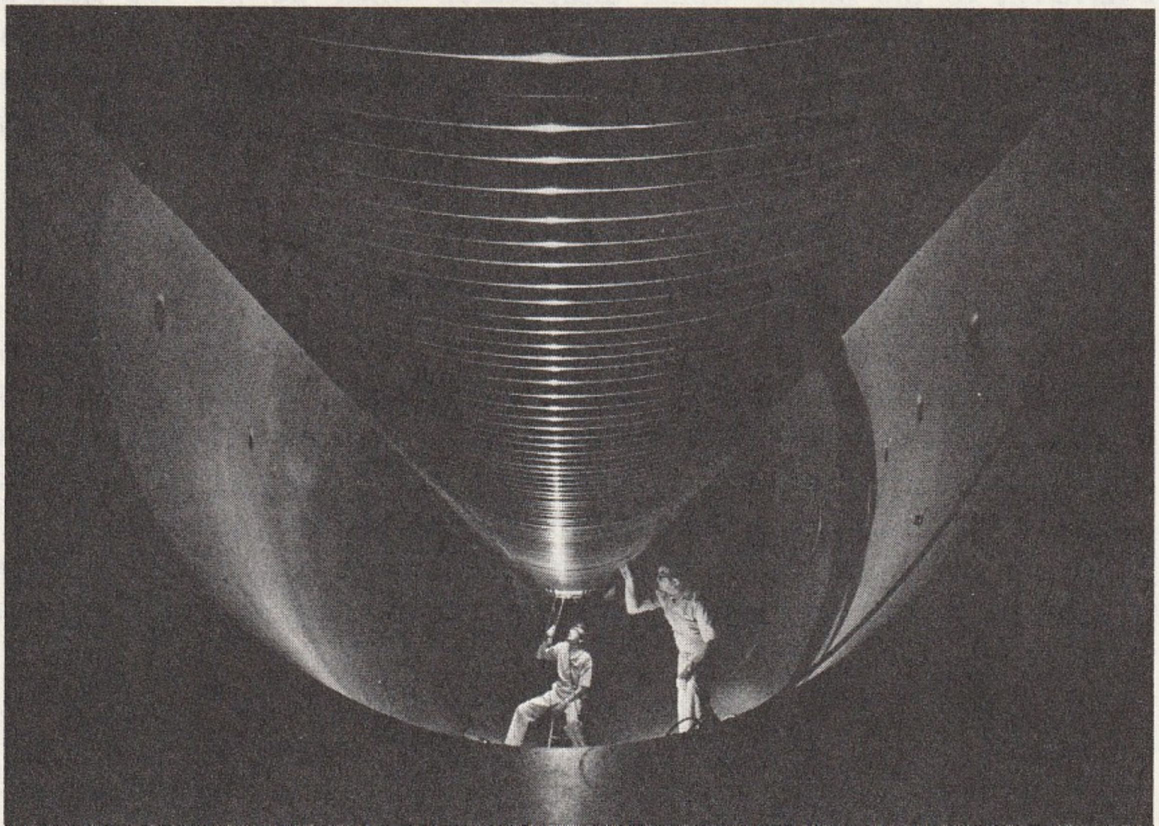
IF MEN COULD FUSE hydrogen into helium under controlled conditions, great quantities of energy would be released for useful purposes. Scientists all over the world are working on controlled fusion devices, and have reached temperatures of several million degrees, although no sustained success from fusion experiments has yet been reported.

Among the heavy elements, where the nucleus consists of a large number of protons and neutrons, the reverse situation applies. The total nuclear mass of these elements, uranium for example, is greater than the mass of the fragments into which it can be split. Therefore, if a heavy uranium nucleus can be broken apart into lighter nuclei, a certain amount of nuclear mass will appear in the form of energy. In the process, some neutrons are freed. Some of the nuclear "glue" or binding energy is released as heat and as beta and gamma rays. The newly created lighter elements are radioactive and themselves "decay", emitting beta radiation, and ultimately changing into a stable form. This, then, is the process of *fission.*

Splitting the Atom

ONE MIGHT ASK HOW, if the atomic nucleus is so small, atomic power can be so great. The answer lies in the fantastically large number of atoms contained in a pound of any material. When an atom of uranium is fissioned, the energy release is 200 million *electron volts*. (The electron volt is a special unit of measurement used by nuclear physicists.) To get enough energy to power ten one-hundred-watt electric light bulbs for one

Inside view of the pressure vessel housing two tandem accelerators at Brookhaven. It is the world's highest-energy Van de Graaff system, and can provide 30 million electron volts of energy for hydrogen ions.



hour, it is necessary to fission approximately 1,120,000,000,000,000 atoms. But there are 11,600,000 times that number in a pound of uranium—enough atoms to light a string of one-hundred-watt bulbs set about two inches apart stretching from New York to Los Angeles.

When the fission, or splitting, of the atom was first achieved, physicists regarded the event as of tremendous significance theoretically because of the aid it gave in understanding the structure and forces of the fundamental particles of matter. But because the atom is so minute and the forces released in fission in the laboratory are so infinitesimally small, no practical applications of the achievement were immediately foreseen.

A New Bullet—the Neutron

JUST AS THE PROTON had been used as a bullet to split the atomic nucleus, so too was the neutron used. Since it was completely neutral, it penetrated matter without being deflected by the electrical charges of protons or electrons. Thus it could travel through the empty space between the atomic particles until it scored a direct hit. When that occurred it could bounce off, to be absorbed by that particle, or cause the particle to split in two—to fission. Prior to 1939, hundreds of such nuclear reactions were produced with various elements. In some cases they even generated more energy than was required to give them their start. But the number of direct hits made by neutrons and the number of fissions produced were heartbreakingly small and it seemed exceedingly difficult—if not impossible—to devise a way whereby the fission process could be put on a self-sustaining basis.

Work with Uranium

IN JANUARY, 1939, the German research team of Otto Hahn and Fritz Strassmann succeeded in fissioning the uranium atom for the first time. They identified one of the products of the fission as barium, element number 56. But it was Lise Meitner, previously an associate of Professor Hahn, who with her nephew, Otto R. Frisch, realized the great importance of the discovery.

Uranium has 92 protons. When it splits, Dr. Meitner reasoned, barium is formed. Barium has 56 protons and this leaves 36 protons for the other fragment, and element number 36 is krypton. But uranium has a mass considerably greater than that of barium and krypton combined.

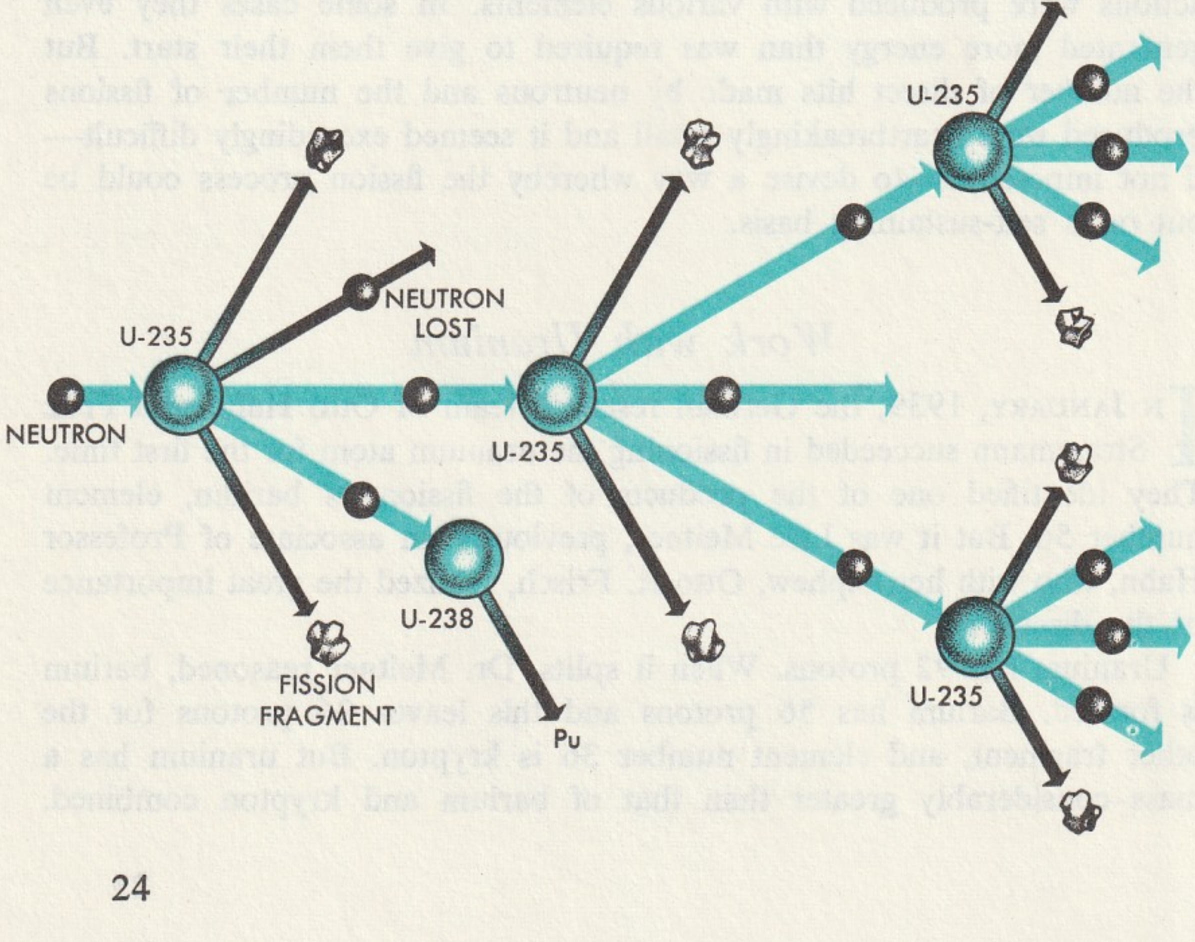
If uranium fissions into barium and krypton, that would mean the release of a tremendous amount of energy, liberated because of the conversion of the mass left over after the fission.

Dr. Meitner went to see Niels Bohr, who was just about to leave Copenhagen for the United States. She reported to him the developments of Hahn and Strassmann and her conclusion concerning its meaning. Bohr carried the news to America and American scientists started to work feverishly to confirm the results.

Since the exact number of protons and neutrons in both the barium and uranium nucleus was known, the Italian physicist, Enrico Fermi, who had arrived in America just a few months before, reasoned that some neutrons were automatically knocked loose in the process. If this were the case, why could not those neutrons be kept from escaping and used to cause more nuclear fissions?

It was concluded, in theory at least, that if enough uranium atoms are present and enough neutrons are available, a point is reached where the neutrons from one fission will cause at least one more fission. This is

FISSION CHAIN REACTION



called a *chain reaction.* It is a self-sustaining process of continuous fission. The quantity of uranium which must be brought together to cause this reaction is called the critical mass. But this was only theory.

The War Years

ON 2 AUGUST, 1939, Albert Einstein signed a letter addressed to President Roosevelt. World War II began on 3 September, but the letter was not delivered until 11 October. Part of this letter is quoted here:

> *In the course of the last four months it has been made probable, through the work of Joliot in France as well as Fermi and Szilard in America, that it may become possible to set up a nuclear chain reaction in a large mass of uranium by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.*
>
> *This new phenomenon would also lead to the construction of bombs, and it is conceivable—though much less certain—that extremely powerful bombs of a new type may be constructed.*

The following year, after many discussions between scientists and government officials, research went forward to determine the suitability of uranium for use as a weapon of war. The problems were many. Since it was not widely used in industry, there was not much uranium available. Up to that time it was used in limited quantities as a glaze for pottery, as a dye or stain for leather and wood, as a photographic toning agent and, of course, in scientific laboratories. Every aspect of this new project was kept secret, and it wasn't easy to buy up all the uranium available without arousing suspicion.

Another problem was the uranium itself. In nature it consists of three types, or isotopes. Each type has the same number of electrons and protons (92 each) but a different number of neutrons. Unfortunately, the most abundant isotope, U-238, which constitutes 99.3 per cent of all natural uranium, can undergo fission but cannot sustain a chain reaction. The second isotope, U-234, is such a small part of natural uranium (.006 per cent) as to be negligible. It was the third isotope, U-235, that held real promise. It can undergo fission and it will sustain a chain reaction. However, in natural uranium, U-235 represents only 0.7115

PRESIDENT FRANKLIN D. ROOSEVELT

ALBERT EINSTEIN

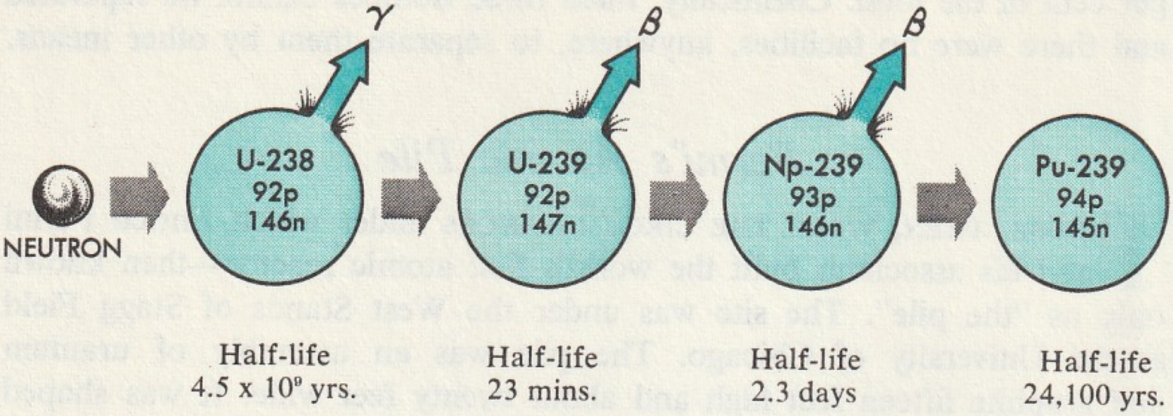
per cent of the total. Chemically, these three isotopes cannot be separated and there were no facilities, anywhere, to separate them by other means.

Fermi's Atomic Pile

THOSE, THEN, WERE THE CIRCUMSTANCES under which Enrico Fermi and his associates built the world's first atomic reactor—then known only as "the pile". The site was under the West Stands of Stagg Field at the University of Chicago. The pile was an assembly of uranium and graphite fifteen feet high and about twenty feet wide. It was shaped roughly like an oblate spheroid, flattened at the top like a door knob, and contained 12,400 pounds of uranium metal. The purpose was to see if a chain reaction, predicted by theory, was possible in practice. The target was natural uranium. The only projectiles available to start the fission process were the neutrons produced by the naturally decaying uranium itself—and these were few indeed. Since it takes billions of years for uranium to decay, dribbling energy only in tiny amounts, the spontaneous fissioning in the pile—one atom here, another there—would be confined to an extremely small number of atoms. These would produce a correspondingly small number of neutron bullets. Since Fermi was trying

ENRICO FERMI

PRODUCTION OF PLUTONIUM 239



to produce a chain reaction, he had to slow down the neutrons to keep them from escaping ineffectually from the pile. This was the purpose of the graphite, which does not absorb many neutrons and therefore is said to have a *low-capture cross section.* Most of the neutrons from the U-235 would bounce off the graphite, lose some of their energy, slow down and—as likely as not—return to the pile. Some would be captured by U-235 nuclei and additional fissioning would occur. But without a strict neutron economy, a chain reaction would certainly not be brought about.

In terms of size and power, the first atomic pile was insignificant. It didn't generate much heat, nor were its radiations powerful enough to

ON DECEMBER 2, 1942
MAN ACHIEVED HERE
THE FIRST SELF-SUSTAINING CHAIN REACTIO
AND THEREBY INITIATED THE
CONTROLLED RELEASE OF NUCLEAR ENERGY

The West Stands of Stagg Field at the University of Chicago.

require that the scientists working on it be protected by shielding. However, despite its insignificant size, it worked.

In December, 1942, Dr. Arthur H. Compton, in Chicago, placed a long-distance telephone call to Dr. James Conant at Harvard University.

"Jim," he said, "you will be interested to know that the Italian navigator has just landed in the New World. The earth was not as large as he had estimated, and he arrived at the New World sooner than he had expected."

"Is that so?" Dr. Conant responded. "Were the natives friendly?"

Dr. Compton's answer: "Everyone landed safe and happy."

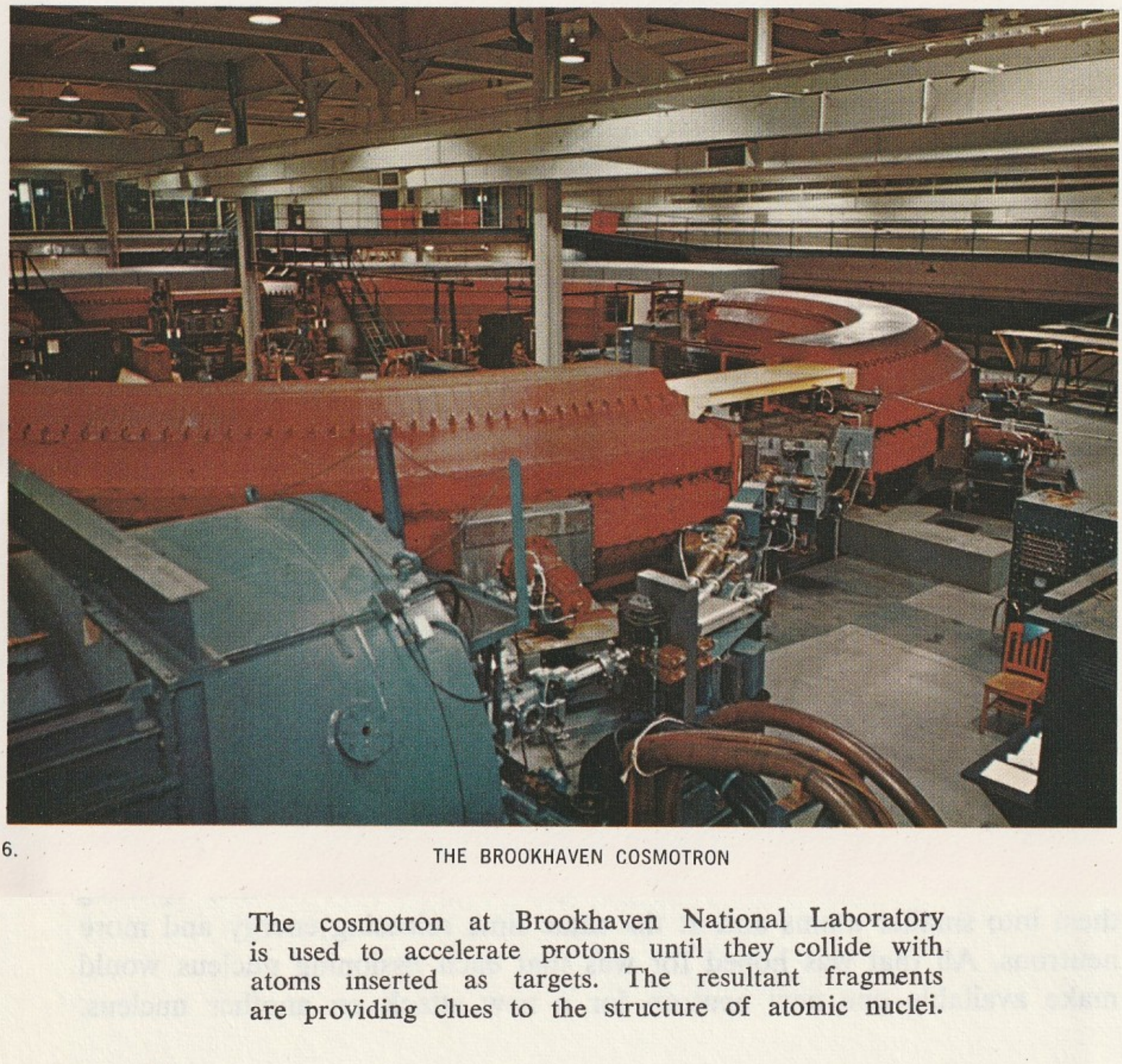
Safe and happy! The unknown dangers had been survived. The power of the atom had been put at the service of man. Atomic energy had been produced and controlled—and a new chapter in science had been opened.

Neutron bullets had fissioned the hearts of U-235 atoms, splitting them into smaller atoms and at the same time releasing energy and more neutrons. All that was hoped for was that each fissioning nucleus would make available one new neutron for a new attack on another nucleus.

Actually the average number turned out to be 2.5 neutrons per fission, a number which insured a plentiful supply of bullets.

The pile yielded other important information. More than 99 per cent of the uranium occurring in nature is the isotope U-238 which is incapable of sustaining a chain reaction. But in the pile, the U-238 nucleus, hit by a neutron bullet, captures the neutron and then transmutes into a fissionable substance, U-239. This artificial and highly radioactive isotope quickly decays, converting itself into the longer-lived plutonium, PU-239.

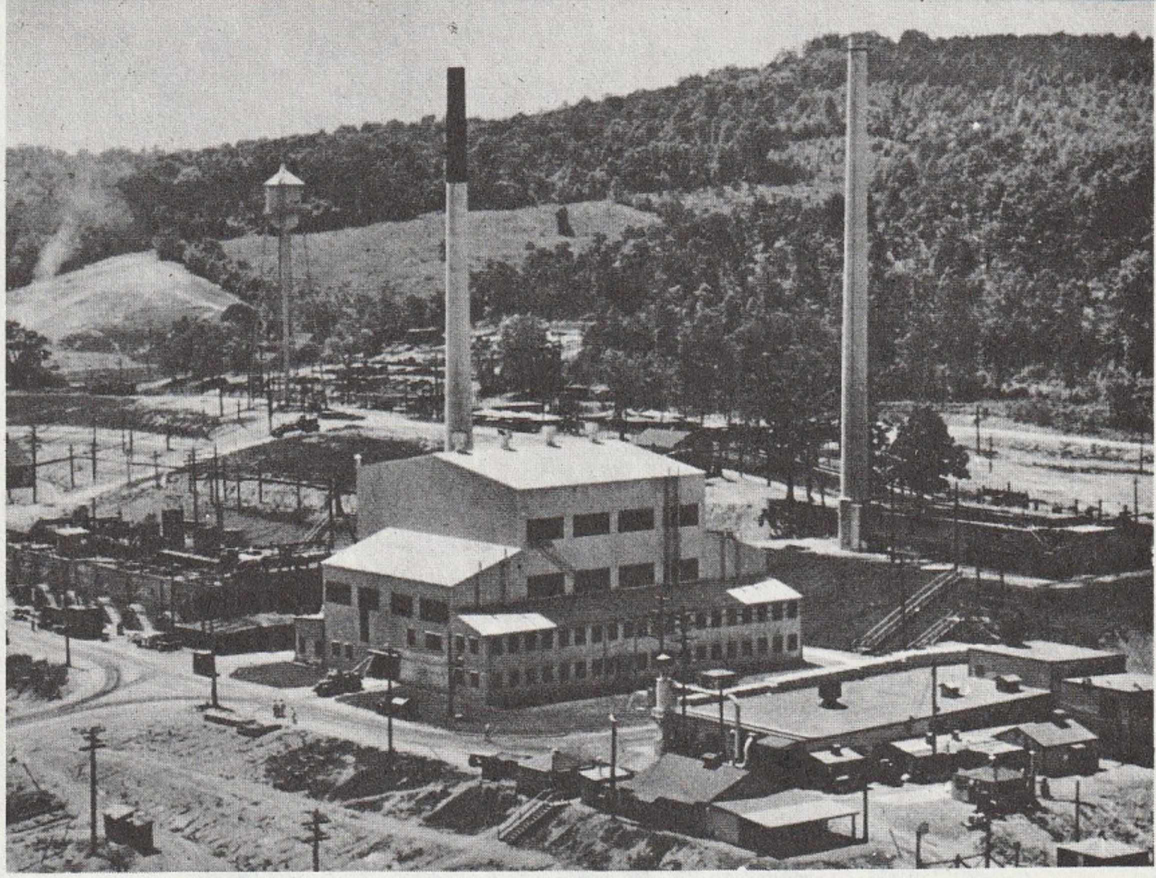
Plutonium does fission. Plutonium does sustain a chain reaction. Plutonium became a new nuclear fuel just as good as the uranium isotope U-235. Instead of one nuclear fuel, there were two. But since the reactor was so small, the amount of plutonium it produced was minute.



6.

THE BROOKHAVEN COSMOTRON

The cosmotron at Brookhaven National Laboratory is used to accelerate protons until they collide with atoms inserted as targets. The resultant fragments are providing clues to the structure of atomic nuclei.

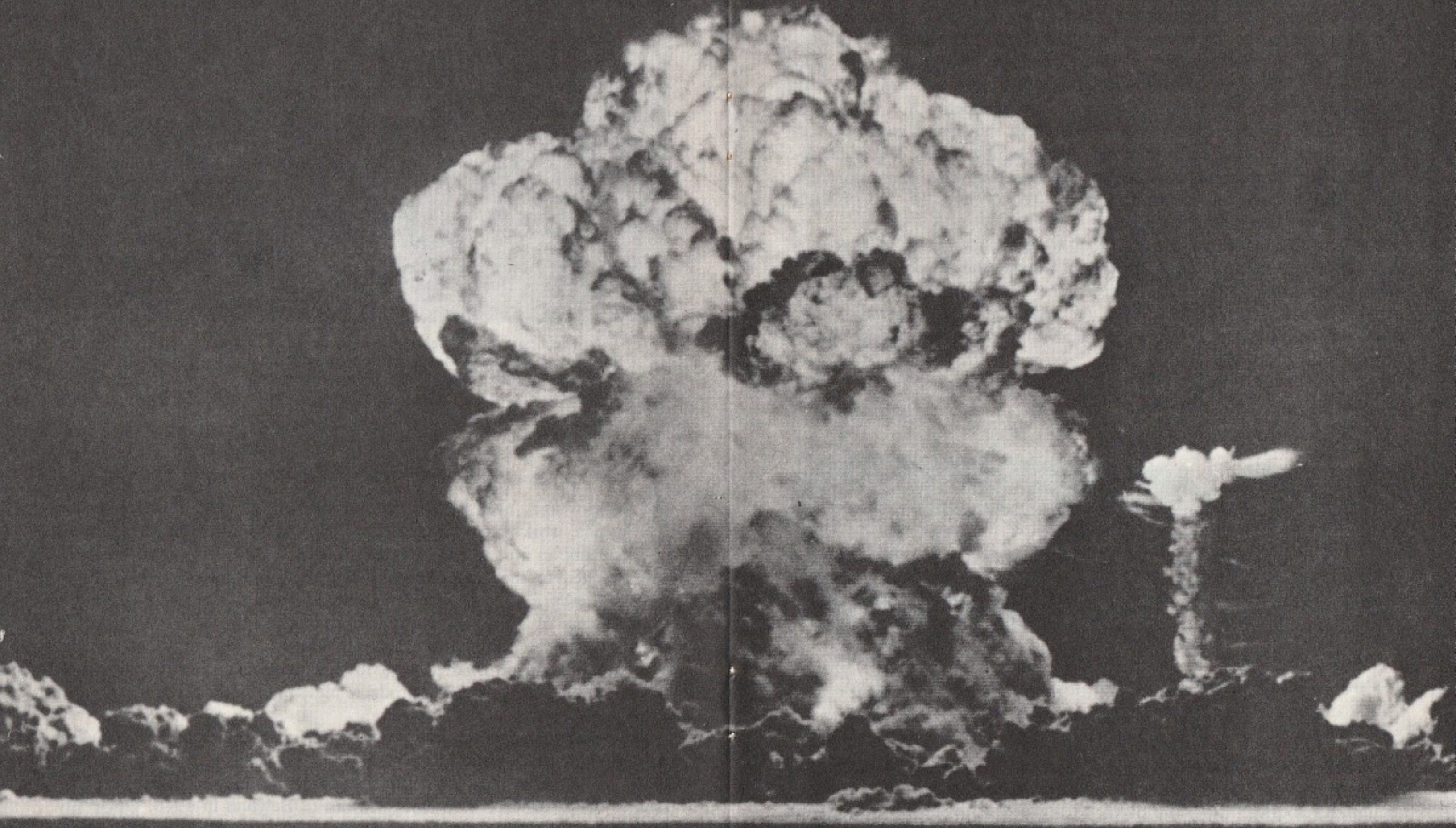


The first uranium reactor to turn to peaceful production—for medicine, biology, agriculture and industry—was located in this plant at Oak Ridge, Tennessee.

The First A-bomb

MEANWHILE, even before the history-making chain reaction in the pile, work had been started secretly on the purely military project of producing an atomic bomb. Production of U-235 and atomic weapons was assigned to the U.S. Corps of Engineers in January, 1942. Major General Leslie E. Groves was appointed to head this work. Full control by the Army of all atomic work was established by April, 1943, under the name of the Manhattan Engineer District. The objectives of the Manhattan Engineer District were to find uranium, mine it, process it, separate the isotope U-235, produce plutonium and, if possible, construct an atomic bomb.

The Manhattan Project was given top priority and unlimited spending powers. Uranium, however, was scarce. Virtually the entire wartime supply of uranium came from the Belgian Congo and consisted of 1,200 tons of ore which had been smuggled out of Belgium in 1940. University laboratories and other scientific institutions determined methods of separating the isotope U-235 from natural uranium, and facilities were



Science Bulletin

Prepared by SCIENCE SERVICE

NEUTRONS AND PI MESONS VS. TUMORS

When X rays are used to kill tumors, they tend to do as much damage to tissues they go through on the way to the tumor as they do to the tumor. Using X rays on deep-seated tumors is therefore a dangerous procedure.

What is needed, says Dr. Max Boone of the University of Wisconsin, is a form of radiation that does little damage on the way in, but maximum damage to the tumor. Such radiation is available in the form of fast neutrons and pi mesons.

X rays damage cells by ionizing atoms, and they do it along their whole path. Neutrons and pi mesons damage by causing nuclei to fission, and they do it only at the ends of their paths. How far the neutrons or pi mesons penetrate before causing fission depends on their energy, so by varying the beam energy the therapist can insure that they will be effective at the level where the tumor lies.

MU MESONS FOR DIAGNOSIS

The mu meson is one of the most unwanted particles in physics. Its properties duplicate those of the electron except that it is 200 times as heavy. The mu meson is unstable; it plays no apparent part in the structure of matter, and it has no place in the schemes and patterns by which physicists try to make sense of the multitude of particles.

Physicists are hard put to find a reason why mu mesons should exist. Nevertheless Dr. Louis Rosen of the Los

Alamos Scientific Laboratory in Los Alamos, Mew Mexico, has found a practical use for them. If a biological specimen is irradiated with mu mesons, he says, study of the pattern of absorption of the mesons will tell what chemical elements are in the specimen. This kind of analysis can be done in a living specimen, and Dr. Rosen suggests it will be useful in making medical diagnoses.

DANGER OF TRITIUM

Tritium, an isotope of hydrogen, is a by-product of nuclear power plants. It is formed both within atomic piles and from neutron bombardment of water molecules in the cooling systems of the nuclear plants. Small amounts are released into the environment as tritiated water.

A University of Chicago radiologist, Dr. Dieudonne J. Mewissen, says that amounts of tritium some fifty times less than the maximum permissible level for power plant effluents, as established by the Atomic Energy Commission, cause cancer in mice.

In a study, Dr. Mewissen gave 1,500 newborn mice either tritium-labeled thymidine, a component of DNA, or normal, non-tritiated thymidine. Mice in the tritiated group had a higher incidence of malignant tumors throughout most of their lifetimes.

Dr. Mewissen says that if the tritium became concentrated in the nuclei of human cells because of an affinity for thymidine, then these nuclei could receive far higher doses of radioactivity than the gross amount of tritium in the body would indicate.

But he admits many more factors must be investigated. These would include: the exact amounts of tritium released from the power plants, the proportion of the tritium retained by the DNA of men and animals, and the varying concentrations of tritium as it advances up the food chain.

SUPERCONDUCTING LINAC FOR HEAVY IONS

For several years physicists at Stanford University have been building a linear accelerator for protons that is designed to use superconducting waveguides for the radiowaves that accelerate the protons. The use of superconducting metals in the waveguides is expected to lead to large savings in the power and time lost to heating caused by electrical resistance in ordinary metals.

Because of metallurgical difficulties, the Stanford physicists have so far achieved only half the amount of acceleration per foot of waveguide that their original plan calls for. Nevertheless their experience convinces them that a superconducting accelerator for heavy ions is feasible and they have begun to design one.

The properties of superconducting waveguides, says Dr. L. R. Suelze, would make such an instrument particularly versatile in accelerating particles with a wide variety of ratios of charge to mass.

MUONIUM IN FREE RADICALS

Muonium is a short-lived substance formed when a muon or mu meson plays the part of an atomic nucleus and captures an electron. The two form a system in which the electron revolves around the muon. Muonium does not last long because muons are radioactively unstable and eventually decay. Muonium is of great interest to physicists since it is one of the simplest systems in which a particle not normally part of an atom plays a quasi-atomic role.

Muonium can form compounds as a normal atom would, and it now appears, Dr. J. H. Brewer of the Lawrence Radiation Laboratory at Berkeley reported, that in some cases it will also form free radicals. Free radicals are highly reactive combinations of atoms that in ordinary chemistry proceed to form further compounds.

Muonium compounds are formed by introducing muons into solutions of different chemicals.

HEATING PLASMA WITH ELECTRONS

Various methods of heating plasmas to or nearly to temperatures at which controlled thermonuclear fusion can take place are under consideration. Electric resistance, shockwaves and turbulence in the plasma are used singly or in combination by many of the experiments now under way in various parts of the world.

To heat a small amount of plasma quickly, the delivery of large amounts of concentrated energy to a small solid pellet of the appropriate substance, either deuterium or deuterium-tritium mixture, is also being tried. In current experiments the energy is delivered by a beam of laser light.

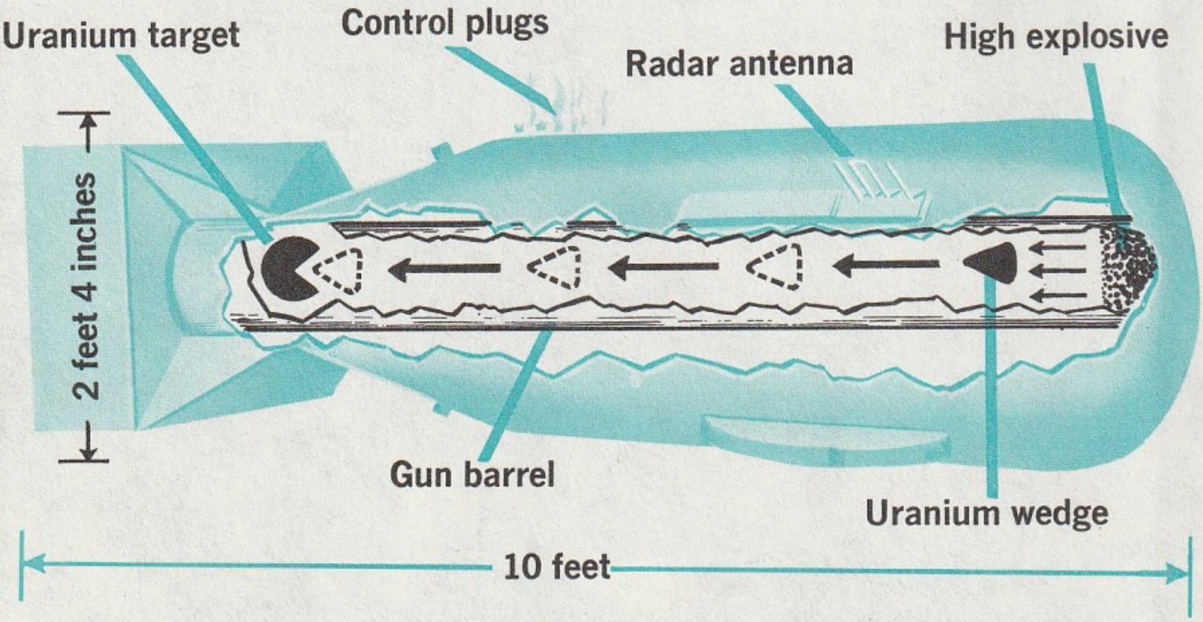
A group of Russians, Drs. M. V. Babykin, E. K. Zavoisky, A. A. Ivanov and L. I. Rubakov of the Kurchatov Institute in Moscow, present a theoretical calculation to show that it can also be done by beams of electrons. Dr. Zavoisky noted that it might be more promising than lasers since the efficiency of transmitting electrical energy from power sources to such an electron beam is greater than it is for lasers.

planned to use these methods. Plans also were made to construct reactors to produce plutonium from U-238 on a large scale.

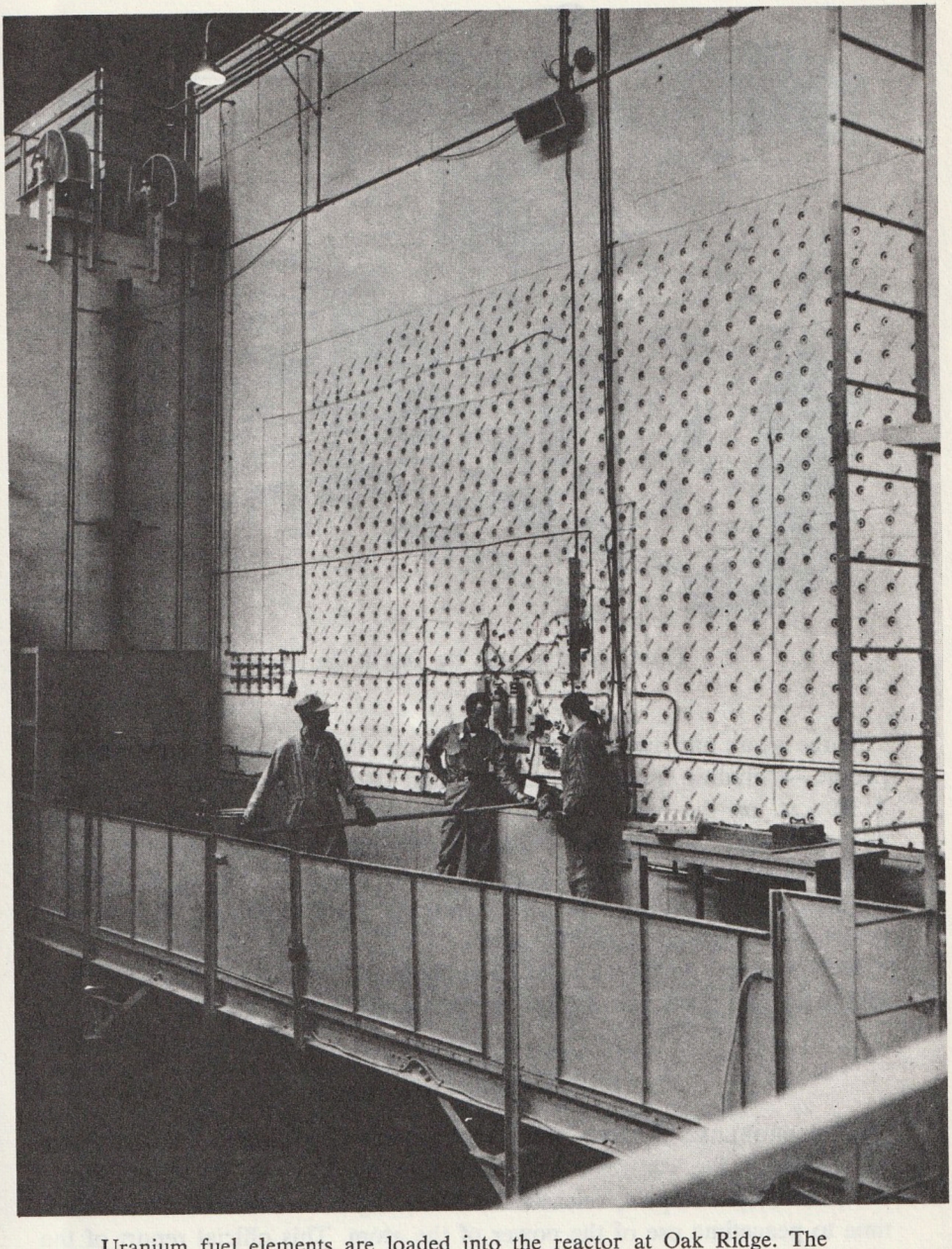
In short order the Manhattan Project acquired a 59,000-acre government reservation in Tennessee. They named it Oak Ridge and it soon became the fifth largest city in the state. Here two plants were built to separate U-235 from natural uranium. A medium-size reactor was also built to investigate the problems of plutonium production.

Across the country, near Pasco, Washington, the Project acquired control of a 1,000-square-mile tract on the Columbia River and built the large reactor complex required for the transmutation of U-238 into plutonium. This became the Hanford Engineer Works, and the city of Richland, Washington, was built nearby.

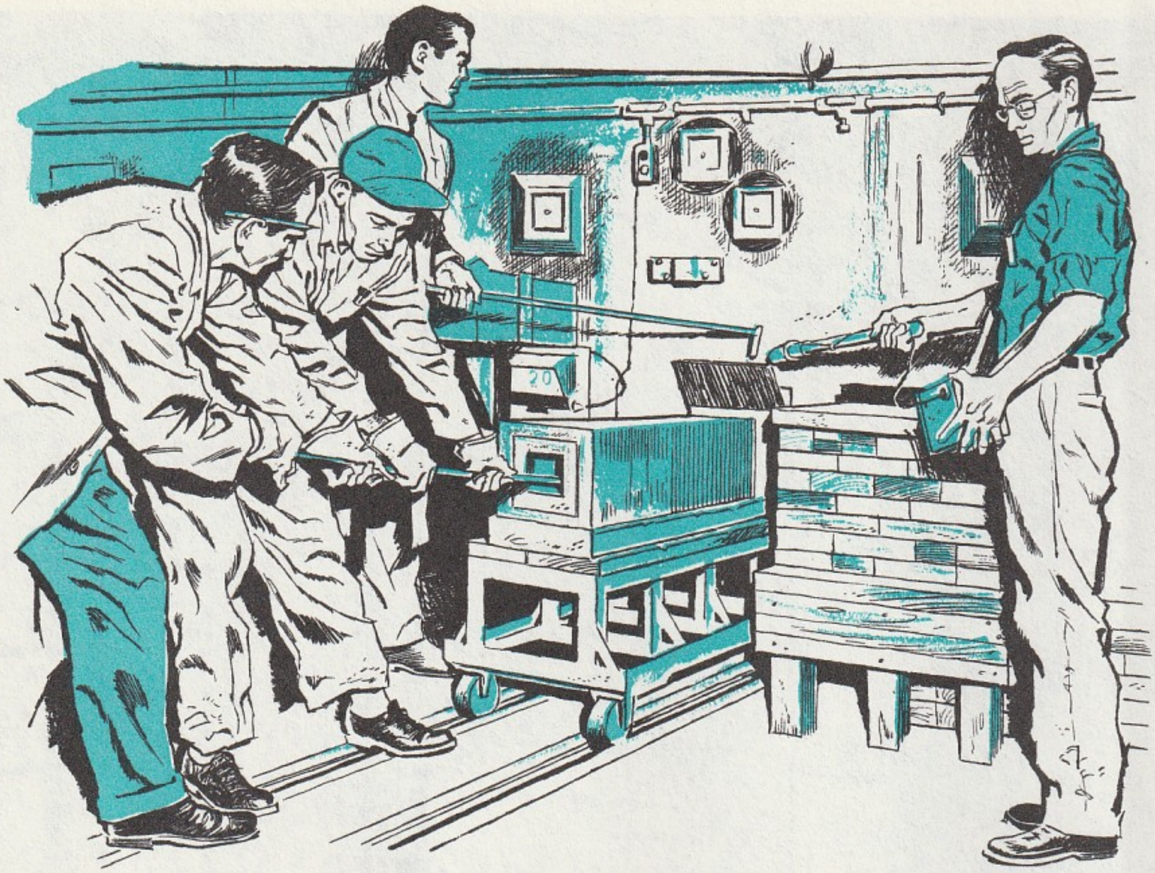
At Los Alamos, New Mexico, the Project obtained a vast area of mesa land and constructed a laboratory. It was the purpose of the Los Alamos Scientific Laboratory to determine how the materials produced at Oak Ridge and Hanford could be fabricated into weapons which could be delivered to a target by plane and which would be safe to handle until dropped.



THE HIROSHIMA A-BOMB – This is a sketch of the world's first atom bomb. Nuclear triggering takes place in a gun-barrel tube. A small wedge of Uranium-235 is driven down the barrel by a chemical explosion into a larger chunk of U-235. The mass becomes over-critical, fissions, and explodes with the force of 20,000 tons of TNT.



Uranium fuel elements are loaded into the reactor at Oak Ridge. The men are standing on an elevator that helps service all the fuel holes.



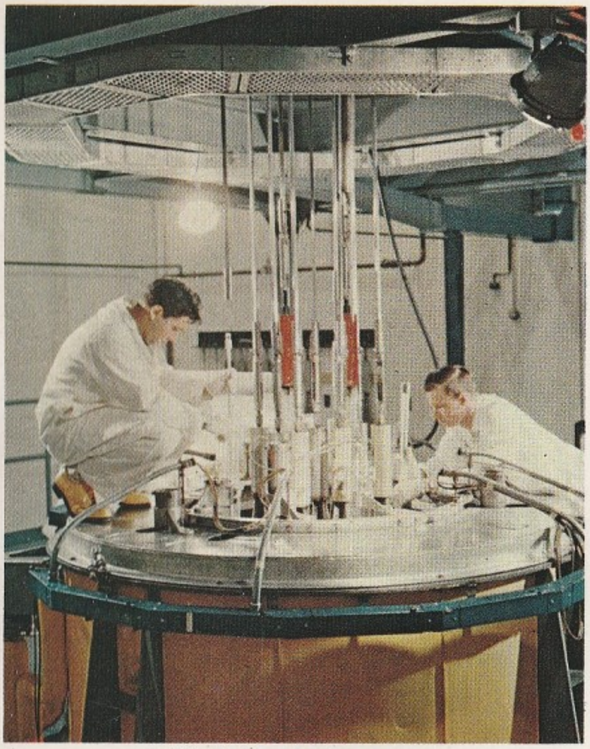
Taking isotopes from the Oak Ridge reactor.

Three years and two billion dollars later, the efforts of some 125,000 people—including many Canadians and British—bore fruit when, at 5:30 A.M. on the morning of 16 July, 1945, the skies of New Mexico above Yucca Flats flashed with the dazzling, blinding brilliance of a thousand suns. There was a searing, racing wave of heat; a shock wave of incredible pressure; an eight-mile-high mushroom cloud; and the desert sand fused into molten glass.

It had been done—and the bombings of Hiroshima and Nagasaki followed; and then the abrupt surrender of Japan in World War II.

From War to Peace

THE PROBLEMS SOLVED, the techniques developed and the know-how gained in the war years were, of necessity, shrouded in secrecy. However, the Smyth Report, released in 1945, began the transition from wartime to peacetime use of the power of the atom. This official report of the Manhattan Project opened the door to the hitherto well-concealed secrets of atomic developments. In 1947 the United States Atomic Energy Commission was established, and as time progressed more and more information was declassified and made available to the public. *Radioisotopes,* as radioactive isotopes were soon called, were made available for medical, industrial and agricultural purposes. Reactors were built at Oak Ridge and at the other National Laboratories to demonstrate their ability to produce power. Finally, the Atomic Energy Act of 1954 allowed the private ownership of power reactors and the facilities necessary to design, manufacture, test and operate them. The atom was coming of age.

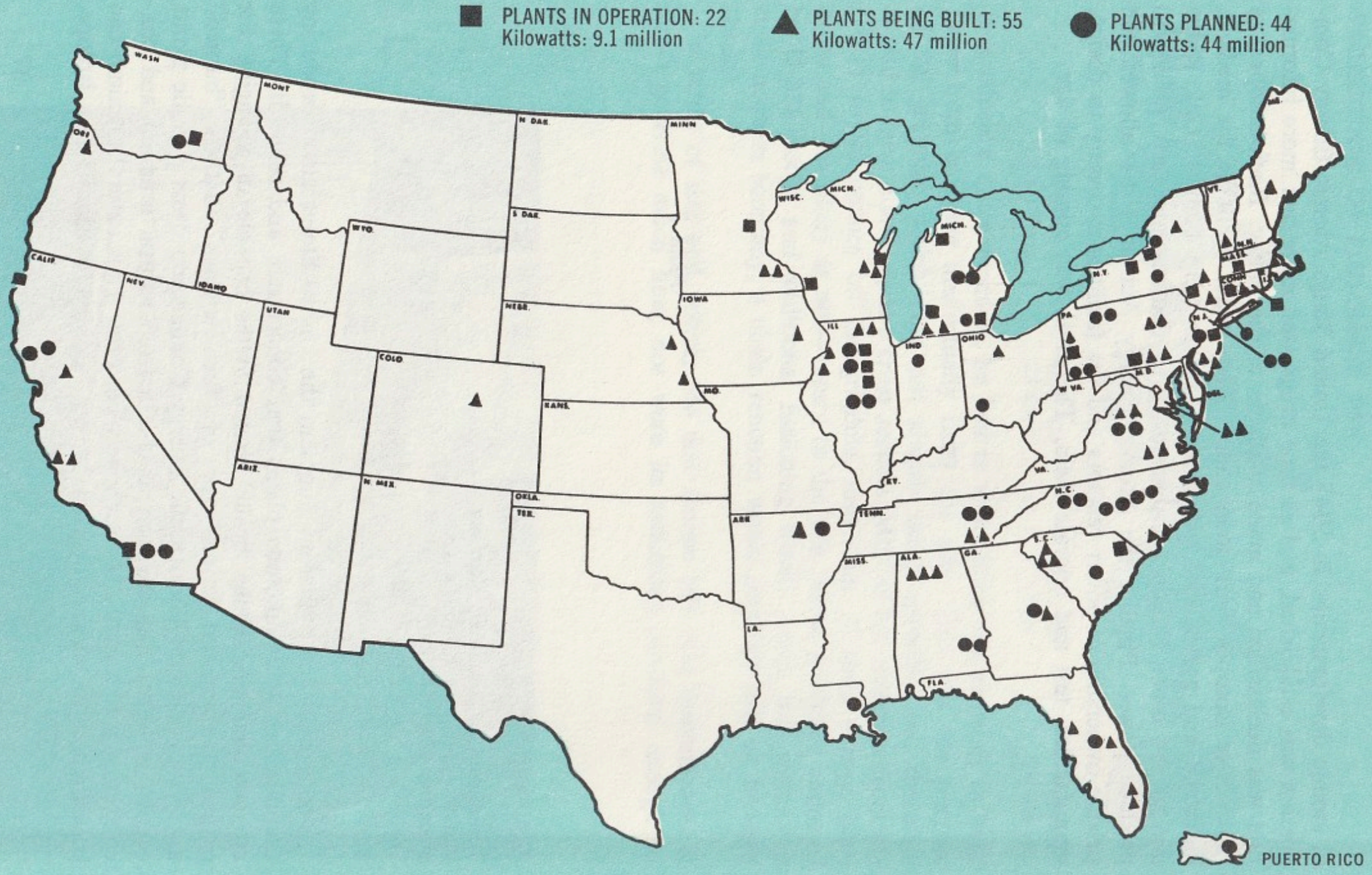


Technicians position fuel elements into the core of a combustion engineering test reactor.

7. AN EARLY TEST REACTOR

Today there are numerous mines in the United States alone producing uranium ore and numerous plants that concentrate and refine it. There are countless companies in the United States capable of changing the refined uranium into various types of "fuel elements" that are "burned" in nuclear reactors. The Atomic Energy Commission owns gigantic plants capable of separating the isotope U-235 from natural uranium and concentrating it to a purity of over ninety per cent. Thus natural uranium can be *enriched* to various degrees by the addition of the U-235 isotope.

NUCLEAR POWER PLANTS IN THE U.S.



Today there are numerous reactors in existence or under construction. How they are being used for peaceful and productive purposes will be discussed later. First let us take a close look at the reactors themselves.

The Heart of the Reactor

WHAT IS A NUCLEAR REACTOR? Had that question been asked in 1942, the answer could have been: a pile of uranium slugs and graphite bars put together to see if a nuclear chain reaction is possible. Today the question is not as easy to answer, since there are numerous types. In simplest terms, nuclear reactors are machines in which atomic energy is released through controlled fission. Many have overlapping functions but each is designed for a specific reason and for a different purpose. However, all reactors have at least one common part. All are built around a supply of fissionable material. This is the heart, or *core,* of every reactor. The rest of the reactor is built around this core. Most reactors generate large quantities of heat which must be removed. A *coolant* absorbs and removes this heat.

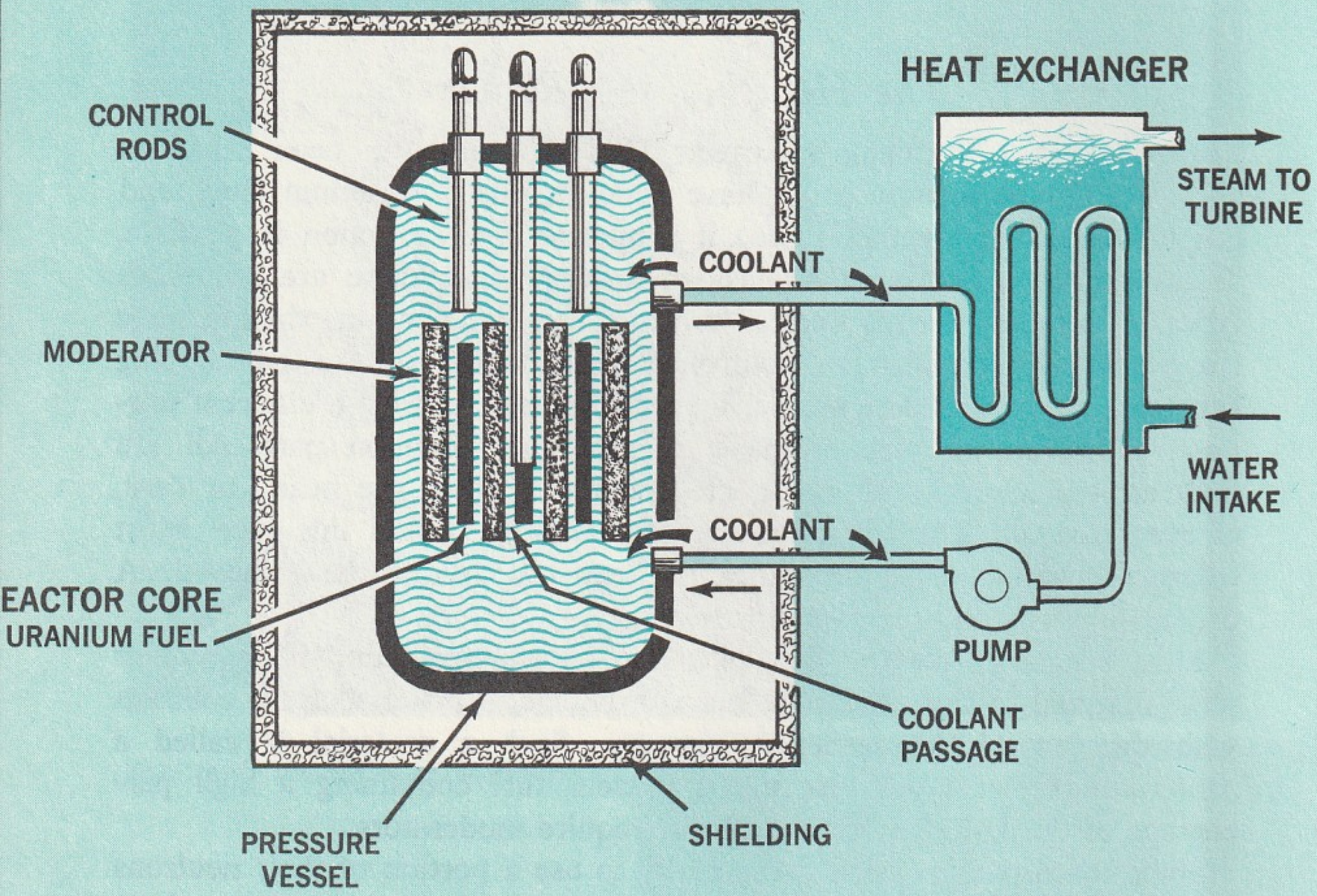
Most reactors, like the first pile, use natural uranium. They require some material to slow down the neutron bullets to make a useful collision with the few U-235 nuclei it contains. Such a material is called a *moderator*. Other types that use a nuclear fuel containing a high percentage of the U-235 isotope may not require moderators.

Some reactors are designed especially to use a portion of their neutrons to change the uranium isotope, U-238, into plutonium. Incidentally, there is another fertile element which can be used as a nuclear fuel. It is thorium. When it absorbs a neutron, in a short time it becomes a new kind of uranium—the man-made U-233. Reactors that change fertile materials in such a manner are called *converter* reactors. Those that produce new fissionable material at a rate faster than they use the fuel in the core are called *breeder* reactors.

Reactors are generally surrounded by a material which prevents the neutrons which have missed the moderator from leaving the reactor. Neutrons bounce off this "wall" back into the core. Such a structure is called a *reflector*.

All these components must be housed in some kind of container, the nature of which depends upon the reactor type. In most cases, this structure is made of steel and is called the *reactor vessel.* Since most reactors generate radiation as well as heat, they must be further surrounded by

HOW A REACTOR WORKS



How a Reactor Works: Basically a reactor is an atomic furnace in which the fissioning or splitting of atoms of nuclear fuel can be controlled and put to useful work. The diagram shows the location of fuel, moderator, control rods, and coolant in a typical power reactor. These components are enclosed within a "pressure vessel" which serves to contain the various parts of the reactor. The coolant, heated to high temperature by the nuclear fuel, flows through a heat exchanger where it turns water in a secondary system of pipes into steam. The steam then is piped to a turbine which operates an electrical generator.

structures which prevent these energies from endangering personnel or surroundings. Such structures constitute a reactor's *shielding*.

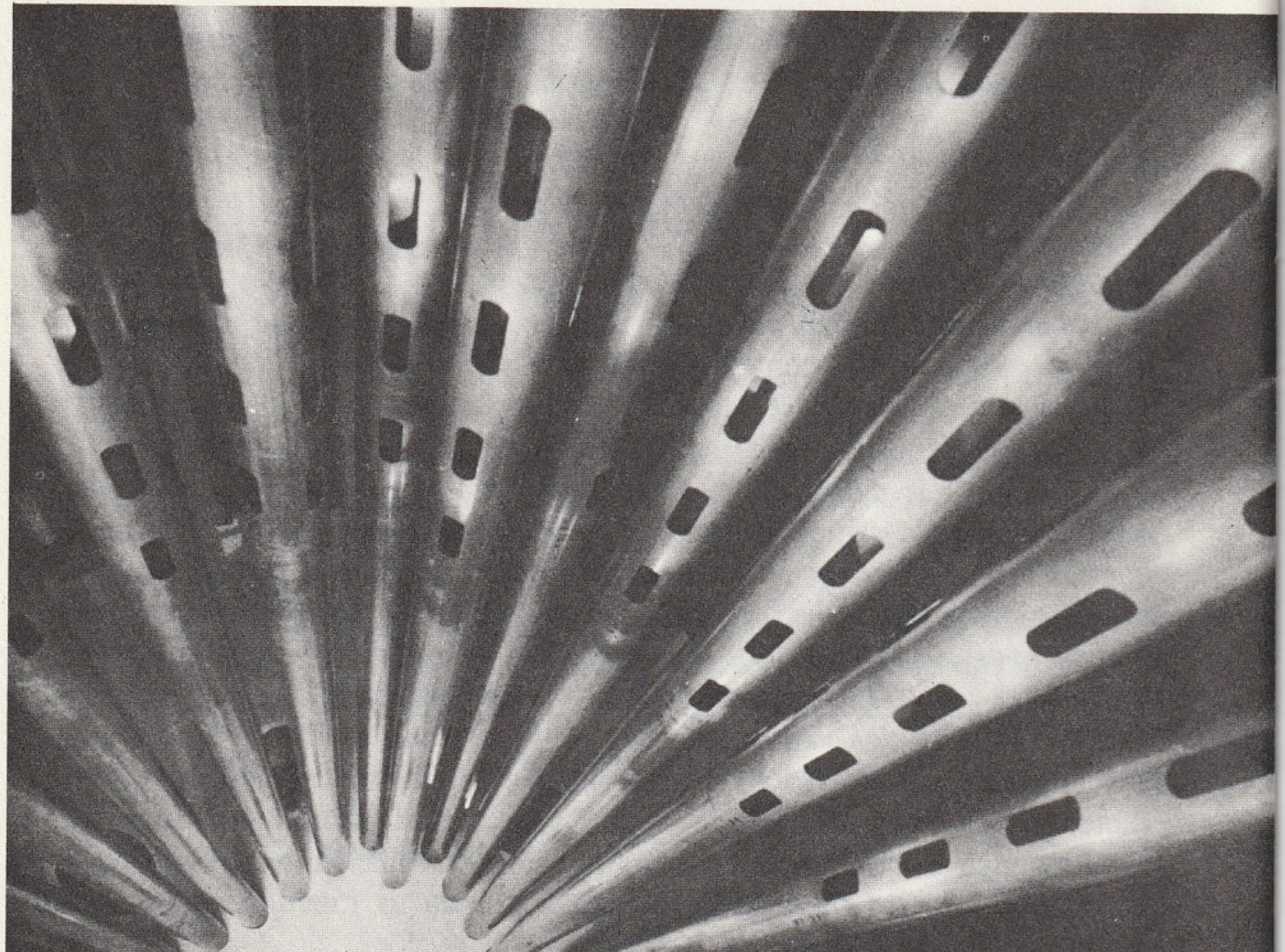
Control Rods

PERHAPS THE MOST IMPORTANT PART of any reactor is its control system. Since a chain reaction takes place in far less time than it takes to blink your eye, the control system must be capable of shutting down the reactor instantaneously and automatically when a condition exists which is either unsafe or capable of becoming unsafe. Most frequently, normal control is exercised by a system of *control rods*. Without them, the assembly of a critical mass of uranium would start a chain reaction, generate ever-increasing amounts of heat, and cause the reactor to melt and possibly permit the escape of various highly radioactive poisons. Control rods, therefore, must be made of a material such as hafnium, boron steel, or cadmium, which will absorb neutrons. Such a material is said to have a *high-neutron-capture cross section*. With the control rods fully inserted in the reactor, neutrons are captured by the rods; the reactor is shut down. When the control rods are withdrawn, neutrons can travel through the core and cause new fissions to take place. By adjusting control rod level in the reactor, it can be made to function to produce varying amounts of heat and radiation.

Kinds of Reactors

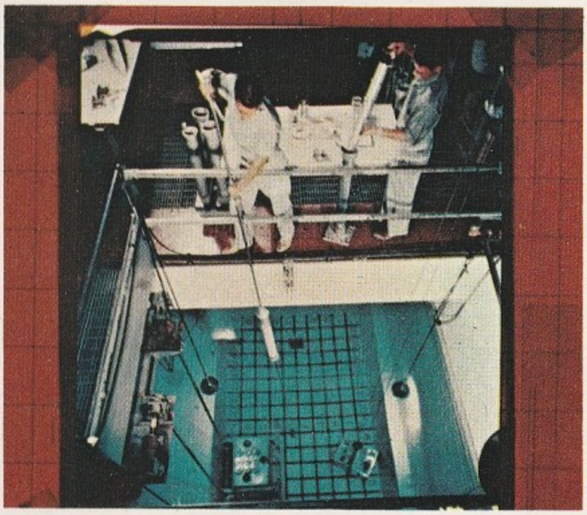
MANY REACTORS, like the first pile, use separate coolants, moderators and fuel. (Fermi's pile used air as a coolant, graphite as a moderator, and natural uranium as a fuel.) Such reactors are called *heterogeneous,* meaning that the fuel is separate from moderator and coolant.

The reactors which use nuclear fuel in the form of small particles suspended in a liquid, and use the liquid itself as a moderator and coolant, are called *homogeneous* reactors. The liquid and the uranium are carried through the reactor system and the fission process goes on all the while, generating heat. The liquid gets hot and is passed through a heat exchanger, gives up this heat and returns to the main core region to start the process anew. This reactor type got off to a slow start because, while it does offer advantages, its power level was hard to control due to concentration of the fuel particles in certain areas causing overheating.



Inside these tubes, or shrouds, control rods of hafnium metal can be moved to regulate the process of atomic fission. Withdrawing the rods increases the number of atoms being split; inserting them reduces the number.

Technicians at Argonne lower food samples into the laboratory's underwater Gamma Irradiation Facility. When placed near spent fuel elements from nuclear reactors and given carefully timed exposures, the food is preserved without need for freezing or dehydrating.

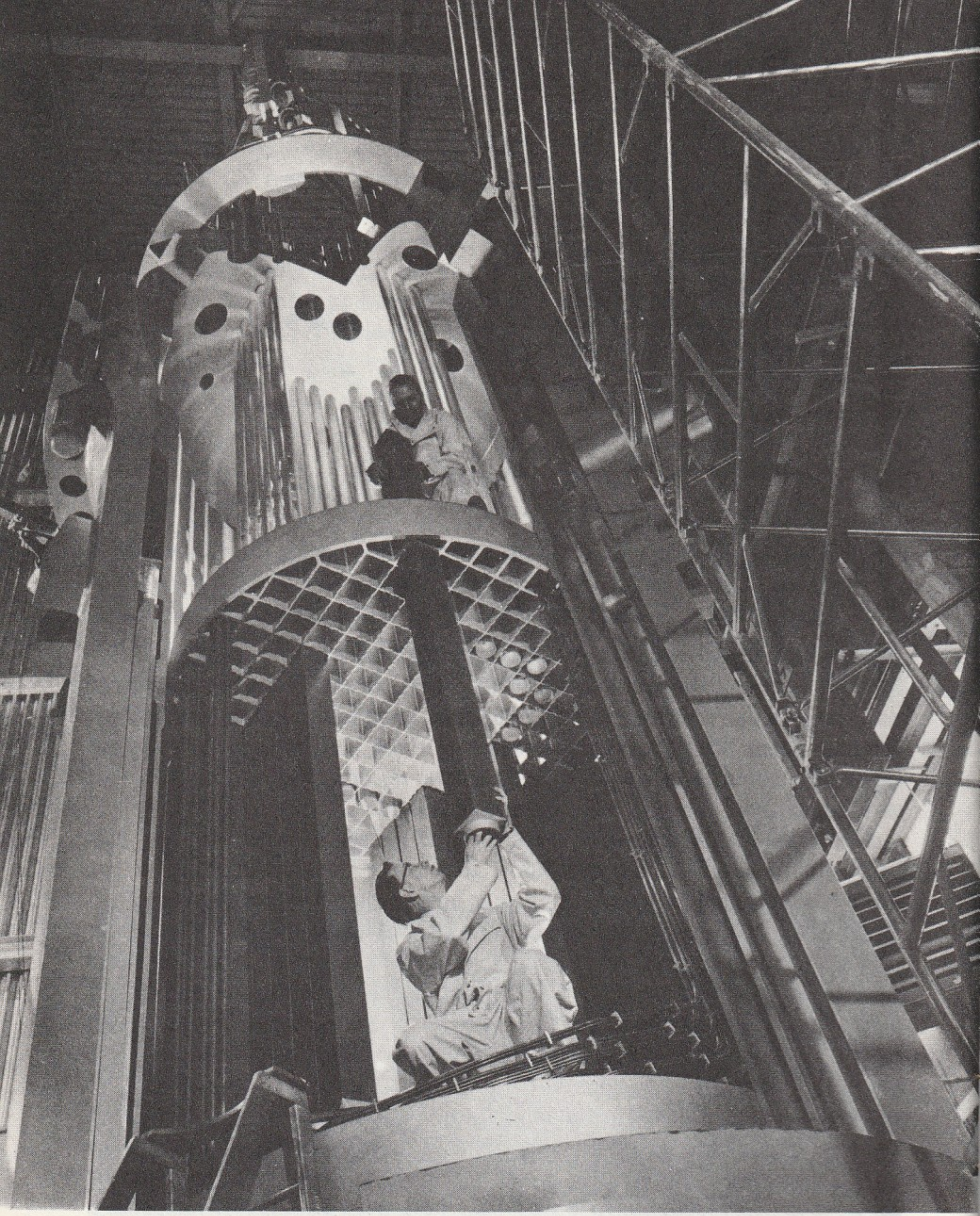


8. IRRADIATING FOOD

Pressurized- and Boiling-water Reactors

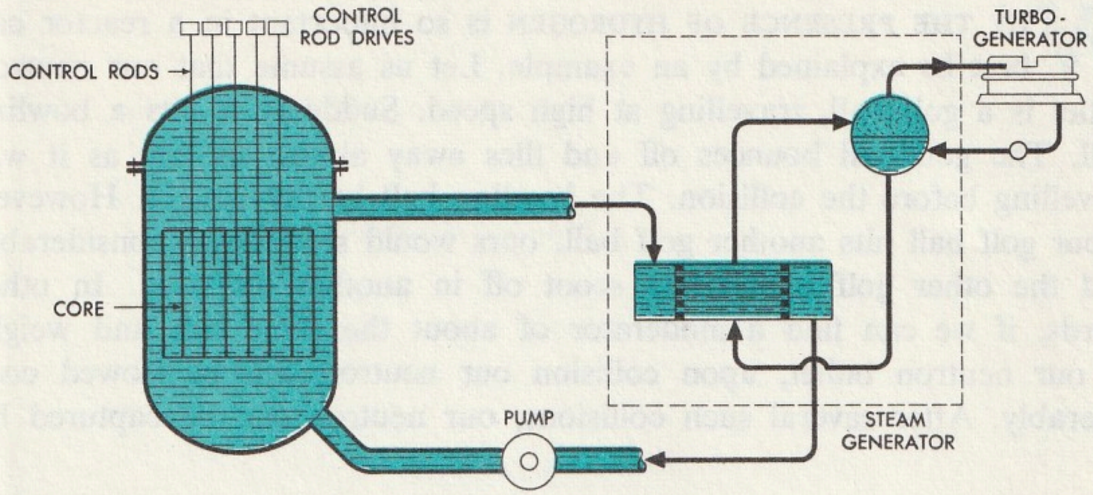
PRESSURIZED-WATER and boiling-water reactors are very similar in certain respects and quite different in others. Both types are heterogeneous reactors and most use a fuel supply of enriched uranium in solid, individual assemblies, through and around which the coolant flows. Both types use water as a coolant, and, where needed, the water also acts as a moderator.

Before the term pressurized water can be properly explained, it is first necessary to review a bit. We know that water in an open pot on the stove (at sea level) boils and changes to steam when it is heated to 212° F. But if we put that water in a completely sealed pot of some sort, that is, under pressure, its boiling temperature goes up. The more we increase its pressure, the higher the boiling temperature becomes, and to make steam we must add more and more heat. For example, in the open pot it boils at 212° F. At a pressure of 100 pounds per square inch, it boils at 338° F. At a pressure of 2,000 pounds per square inch, it will not boil until it reaches a temperature of about 636° F. So we can see that pressurized water can absorb a lot of heat without turning into steam. Thus we can circulate it, have it pick up heat from the reactor core, leave the reactor, give up its heat in a heat exchanger, and return at a much lower temperature. The heat it has given up can be used for doing work. The water in the reactor is circulated in one end and out the other in a continuous flow and does not come in contact with any machinery or equipment outside the reactor system.



Inside this full-scale mock-up of the type of pressurized-water reactor installed at the Shippingport atomic power station, a wooden fuel element is moved into position. In the actual reactor, heat is generated by a core consisting of fourteen tons of natural uranium surrounding about 165 pounds of highly enriched uranium "seed".

PRESSURIZED-WATER REACTOR



The boiling-water reactor is essentially the same, except that it is not so highly pressurized. Water is allowed to boil and the steam it produces is used without an intermediate heat exchanger.

Slowing the "Bullets"

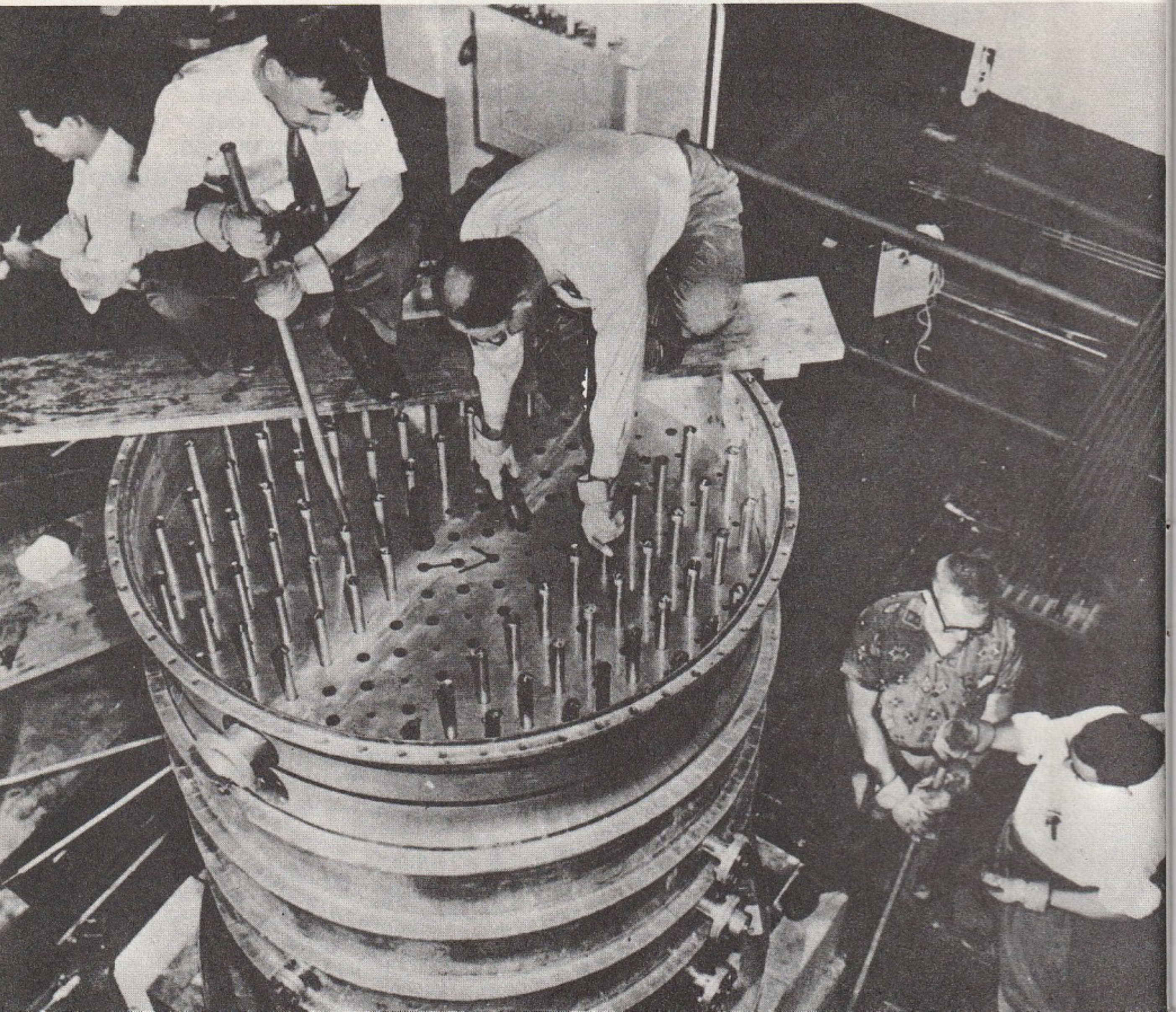
AS PREVIOUSLY EXPLAINED, a moderator slows down neutrons. The first pile used graphite as a moderator. Pressurized-water and boiling-water reactors, which normally use enriched uranium fuel, can use ordinary water. But there are other moderators. The metal beryllium is one. Another, about which you have probably heard much, is *heavy water*. Heavy water (D_2O) differs from ordinary water (H_2O) in that the heavy water molecule consists of atoms of oxygen and the hydrogen isotope deuterium. (The deuterium nucleus contains one proton and one neutron. The hydrogen nucleus in plain water contains only the proton.) Heavy water absorbs fewer neutron bullets than does ordinary water and hence is an effective moderator. It is very expensive, however, and generally it takes more heavy water than light water to get the desired slowing action. Like water, it is both a moderator and coolant and can be used in either pressurized-water or boiling-water reactors.

It is interesting that the moderators most commonly used in enriched uranium reactors rely on compounds which contain some form of hydrogen. This is because the bullet, the neutron, is very small and has a very short lifetime in a reactor (about one one-thousandth of a second in a reactor using slow neutrons). It is important, then, that the bullet be slowed down as quickly as possible.

Importance of Hydrogen

WHY THE PRESENCE OF HYDROGEN is so important in a reactor can best be explained by an example. Let us assume that our neutron bullet is a golf ball, travelling at high speed. Suddenly it hits a bowling ball. The golf ball bounces off and flies away almost as fast as it was travelling before the collision. The bowling ball hardly budges. However, if our golf ball hits another golf ball, ours would slow down considerably and the other golf ball would scoot off in another direction. In other words, if we can find a moderator of about the same size and weight as our neutron bullet, upon collision our neutron will be slowed considerably. After several such collisions, our neutron can be captured by

A small heavy water exponential reactor is used by students of the Argonne National Laboratory.



9. TILLING AN ATOMIC FARM

When no people are in this field at Brookhaven, radioactive cobalt is raised inside the pipe by remote control. The cobalt gives off gamma rays which cause genetic changes in plants grown in the field. Some of these changes may continue in successive generations and may be useful.

the U-235 nucleus. Of course, the nearest thing in size to our neutron bullet is the proton, which is the nucleus of a hydrogen atom.

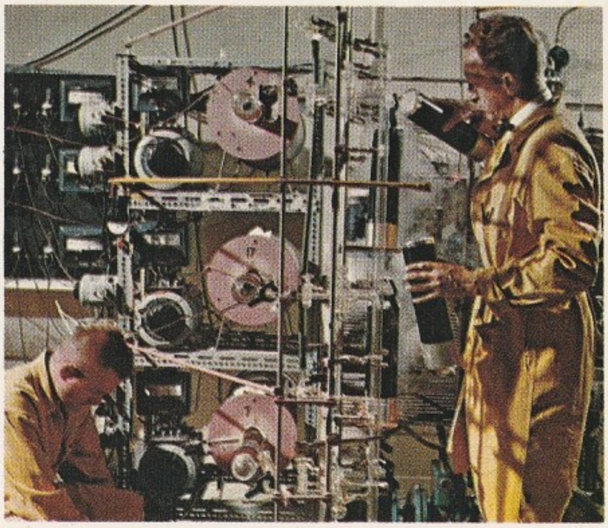
This also helps explain why heavy water is used as a moderator. Since deuterium already has a neutron, it doesn't readily absorb another. However, the heavy water nucleus is a bigger nucleus, so when our neutron hits it, it is not slowed down as much as when the neutron hits a regular hydrogen nucleus. This explains why it requires more heavy water to slow down the neutrons.

This also explains why graphite moderated reactors are generally large structures. With a graphite moderator, the neutron speed lost in each collision is relatively small, and the distance travelled between collisions is relatively great.

Organic compounds containing hydrogen have come into use as a combined moderator and coolant. They are not corrosive. They do not become highly radioactive. Some, however, do have a tendency to break up, or decompose, when subjected to the intense radiation in a reactor.

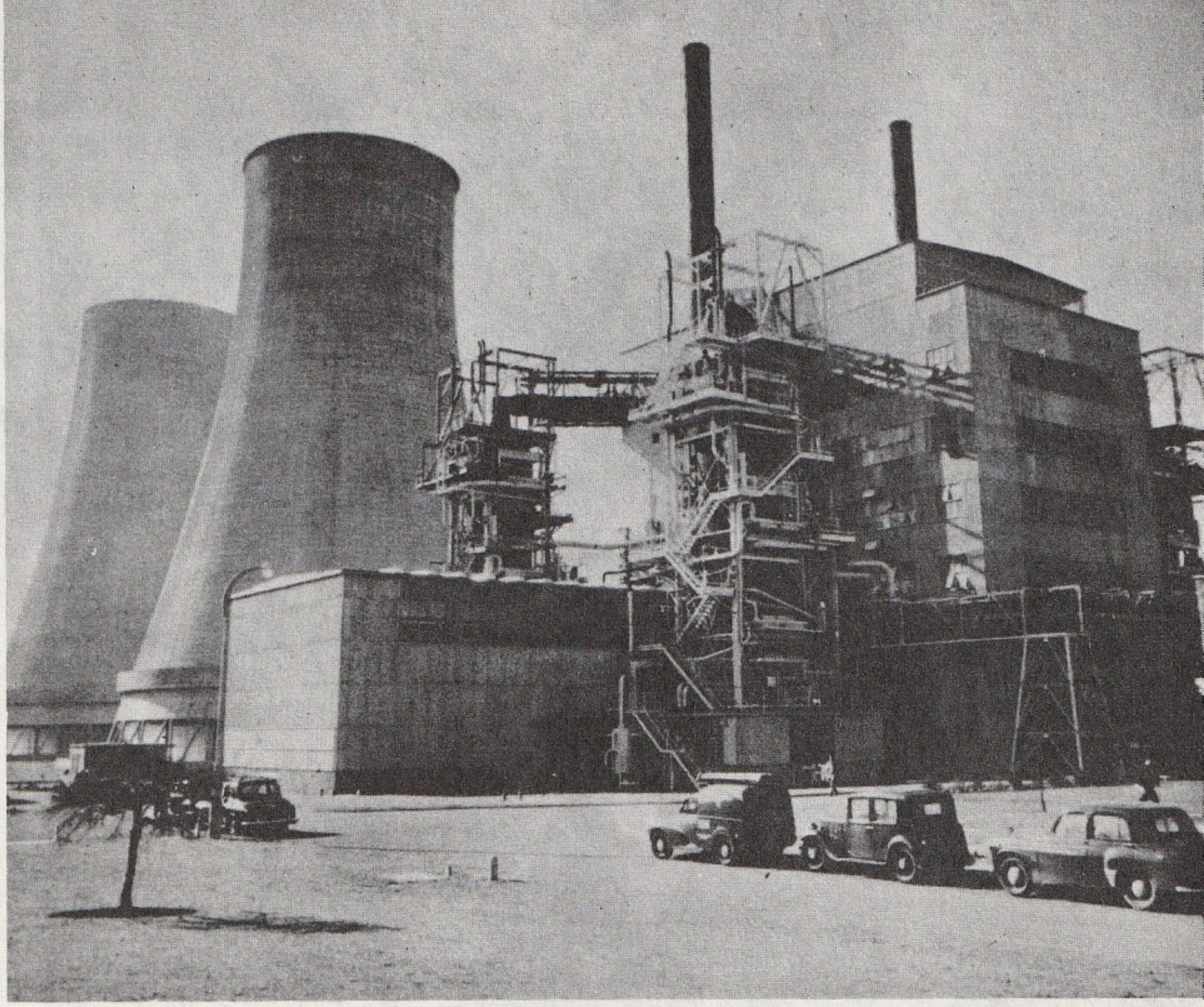
Coolants

JUST AS THERE ARE several moderators in use, there are also a number of coolants available. As already mentioned, the same fluid serves both functions in some cases. Among other coolants are liquid metals and the gases carbon dioxide and helium. Again, each has certain advantages and each has drawbacks. The liquid metal sodium, for instance, has a very high boiling point and can absorb a great amount of heat from the reactor core. Therefore, when pumped to a heat exchanger, it can do more work. It can make more steam and at higher and more efficient pressures and temperatures. Sodium is an especially good coolant in a reactor that uses highly enriched uranium. Such a core is generally quite small, yet produces a lot of heat. Since sodium has such good heat transfer properties, it is an effective coolant. Another advantage is that, because it is not pressurized, it does not require the enormously thick and heavy reactor vessel normally associated with water reactors. Its disadvantages are that when bombarded by neutrons, it becomes radioactive. In addition, it reacts explosively with water and oxygen. For these reasons it is necessary to contain it in such a way that it will neither leak nor come into contact with water. Furthermore it solidifies at room temperature



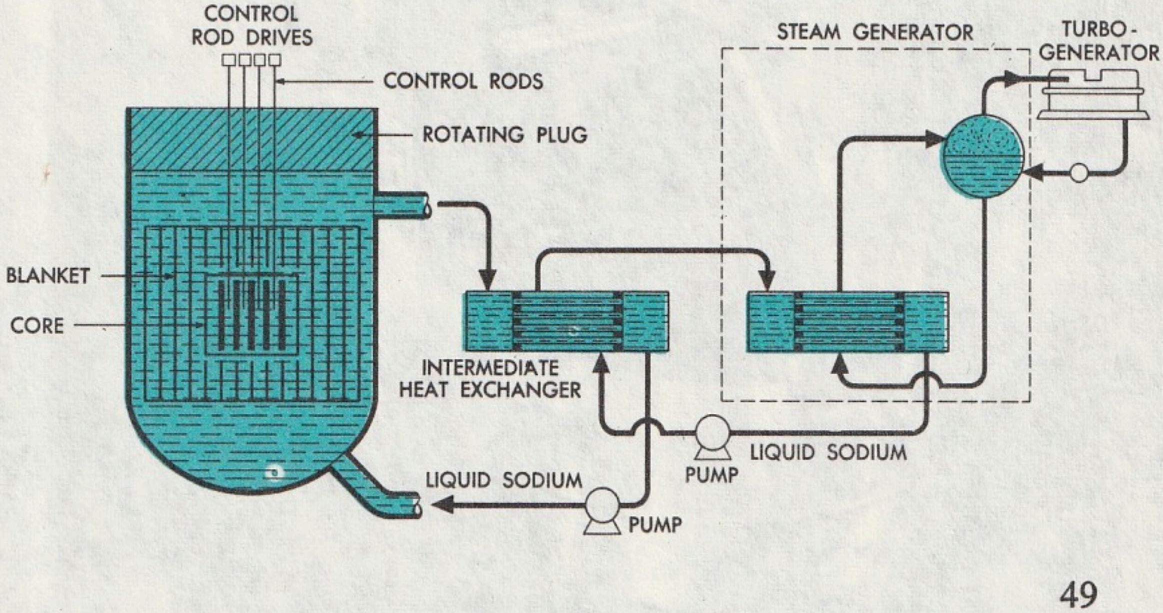
Two technicians are preparing a semihomogeneous fuel element in the Hydride Laboratory of the General Atomic plant in San Diego. In this fuel element, the hydrogen moderator is intimately mixed with fissionable material.

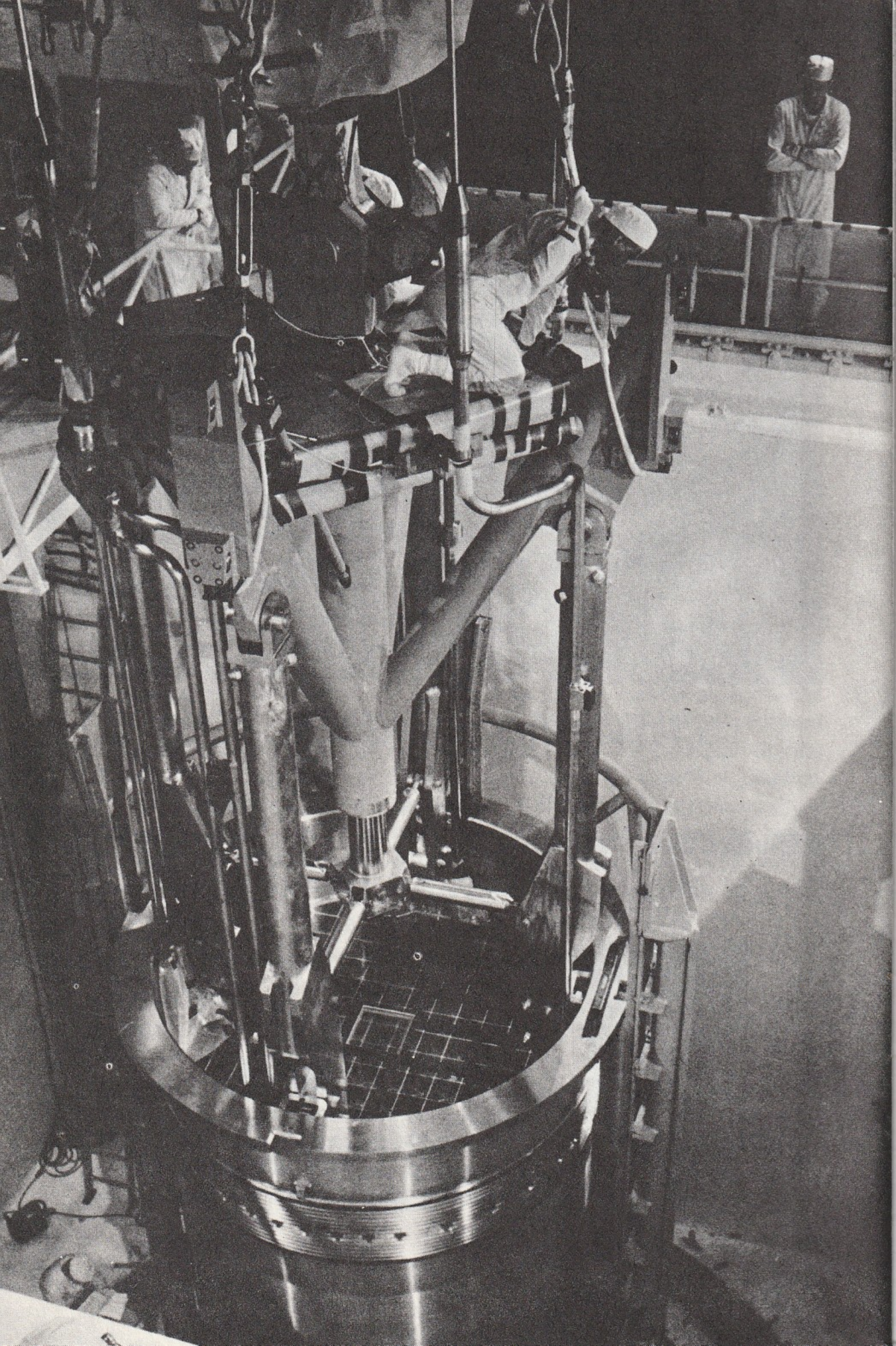
10. MANUFACTURING A FUEL ELEMENT

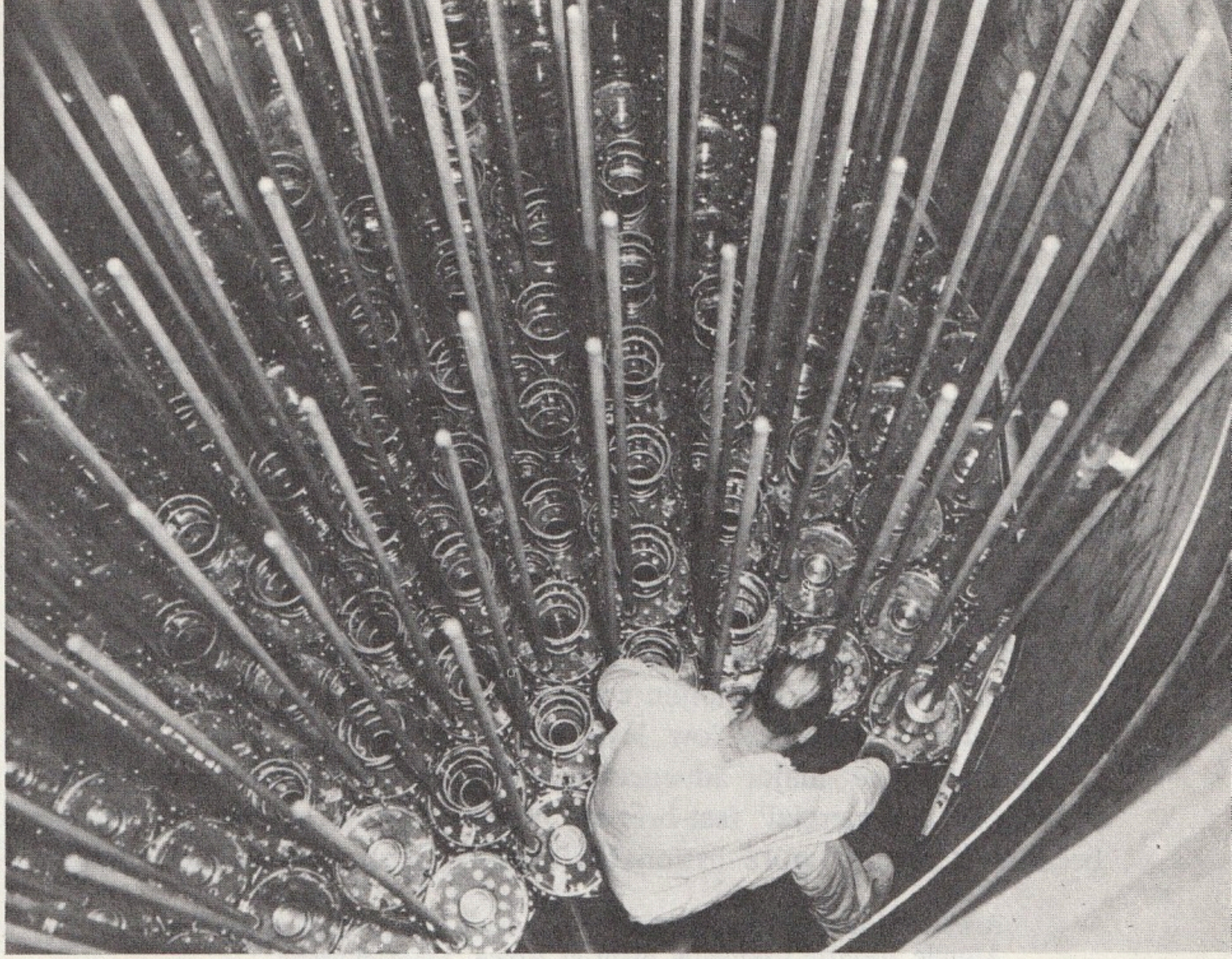


Britain's first atomic power station, Calder Hall in Cumberland, started producing electricity in 1956, when this photo was made.

SODIUM-COOLED REACTOR







Looking into the heart of the reactor core of the Sodium Reactor Experiment, built by Atomics International in Canoga Park, California. The 119 moderator cans spaced in the cylindrical tank are filled with graphite. The coils on top of the cans guide the fuel elements into their tube openings during refueling.

and requires a heating system to keep it in liquid form. Without such heaters, the sodium would solidify when the reactor was shut down for any reason. Other coolants in wide use for power-producing reactors, especially in Europe, are inert gases such as carbon dioxide and helium.

The Atom for Peace

MANY MILLIONS ALREADY USE electric power derived from atomic energy. Nuclear power plants, virtually unheard of fifteen years ago, are now a commercial reality. In the United States alone, twenty-two power plants were operating at the end of 1971, fifty-five were under con-

Left: A view of the atomic reactor at Shippingport. Here a giant overhead crane is used to position the core barrel inside its reactor vessel.

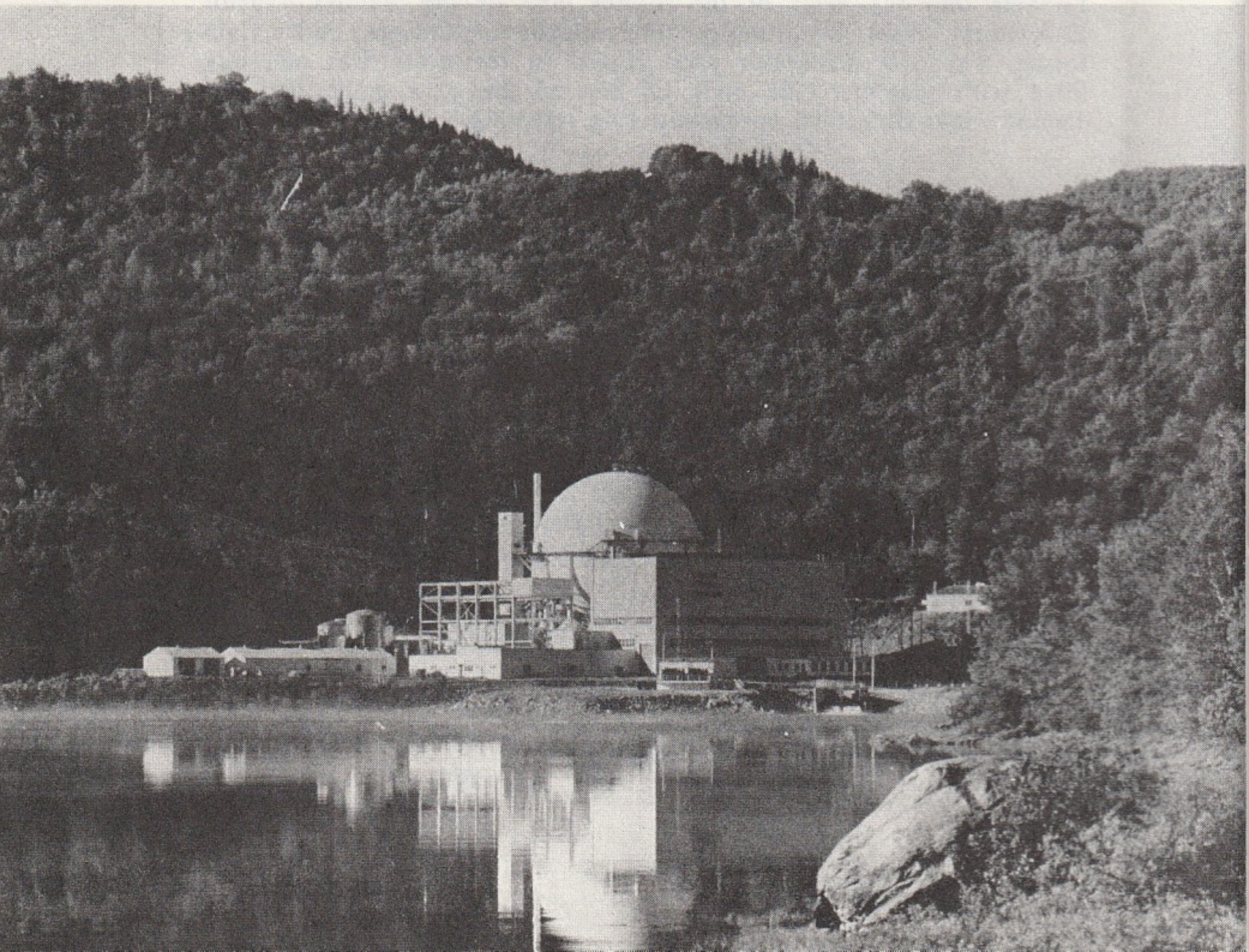
struction, and forty-four more were in the planning stage. Britain had twenty-nine in operation, Russia eleven. Throughout the rest of the world more than 350 atomic power plants were operating or being built.

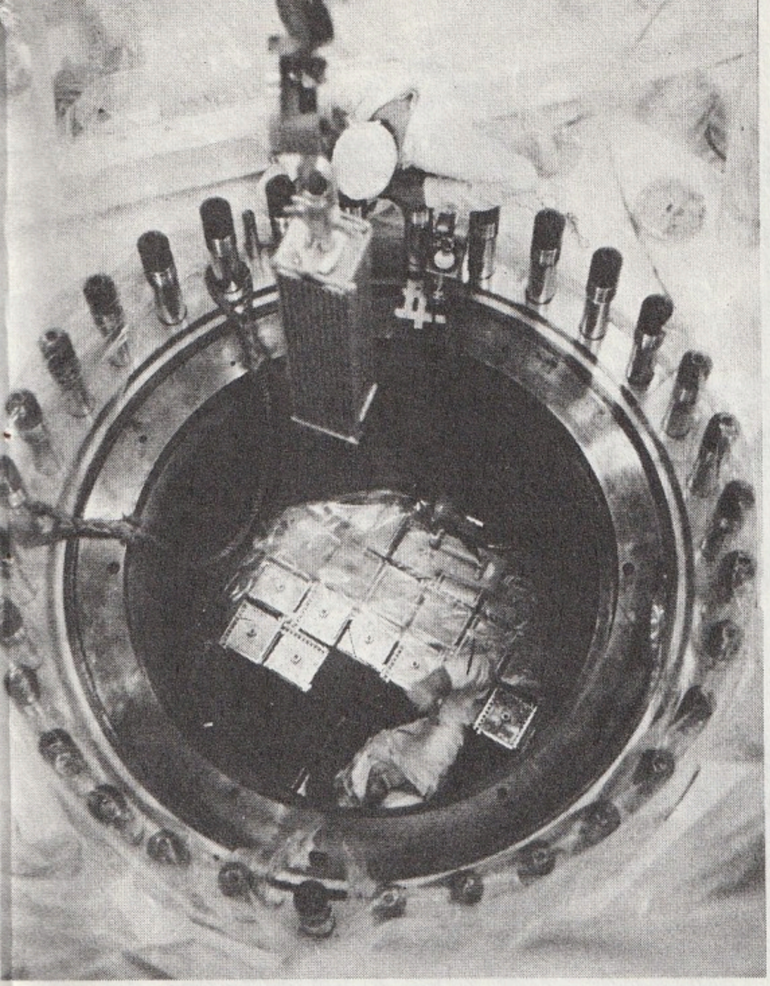
The first full-scale nuclear power plant in the United States was built at Shippingport, Pennsylvania, in 1957. Today atomic power generators provide five per cent of the total power needs of the U.S. By 1980, the atom may be supplying twenty-five per cent. At this rate, nuclear energy may account for half of all the electricity produced in America by the turn of the century. The forecast in Great Britain and other countries of Europe is equally impressive.

Four factors favor the growing acceptance of nuclear reactors for electrical power: the economic competitiveness of large plants; reliability; safety; and a relatively low level of air pollution.

Looking ahead, major advances can be expected in the development of the large commercial fast-breeder reactor. It is called a "breeder" because it creates more fissionable material than it consumes. Scientists

A modern nuclear power plant in a sylvan setting. This is the Yankee Atomic Electric Company plant at Rowe, Massachusetts.





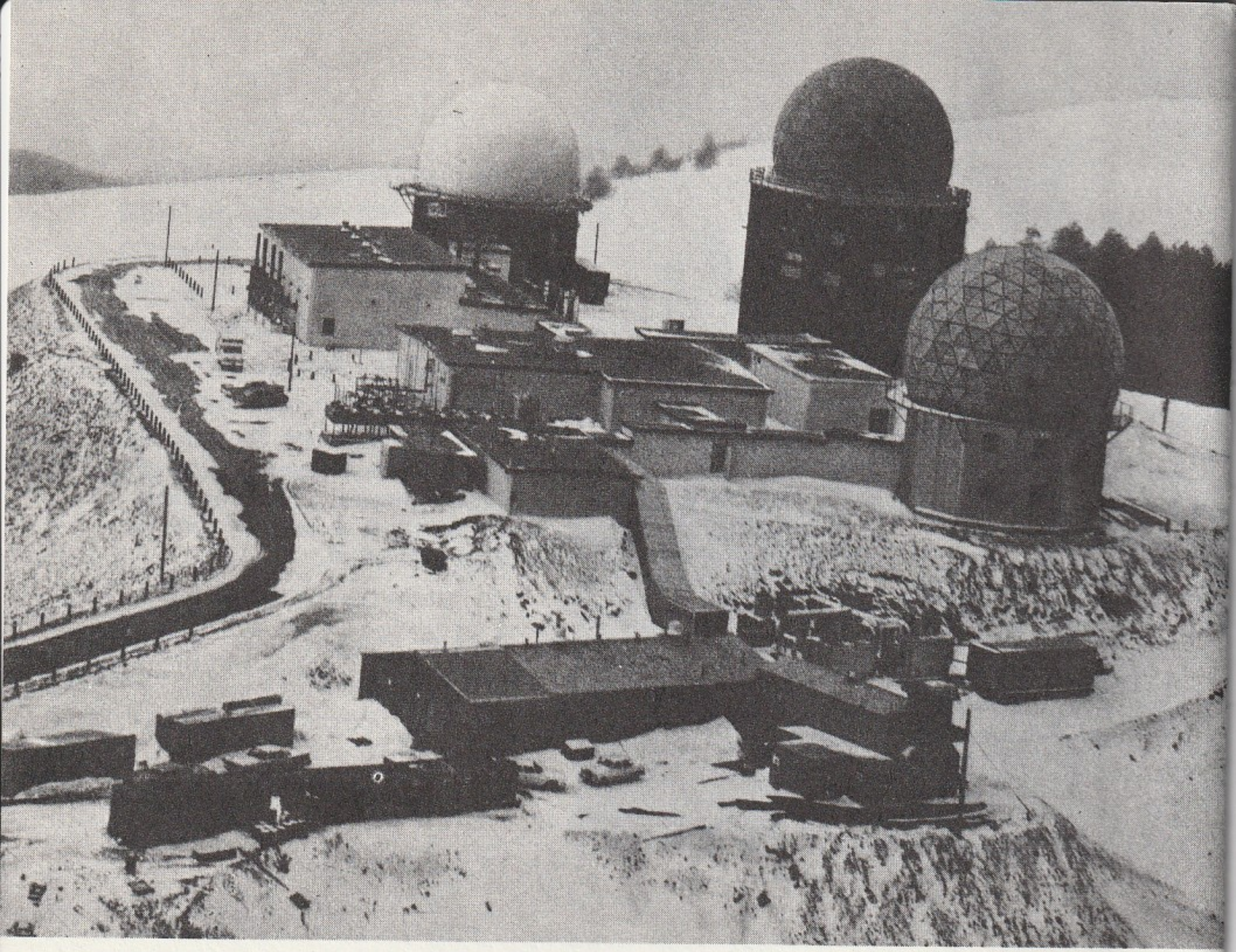
Fueling a nuclear furnace. One of thirty-two nuclear fuel elements which compose a reactor core is lowered into place.

are looking to fast-breeder economy in the 1980s that will bring vast savings in costs and fuel resources.

Coming years will see further advances in the field of thermonuclear fusion, which liberates energy by fusing some of the lightest atomic nuclei, as opposed to releasing it by splitting heavy nuclei, as in the fission process. The fusion reactor—if it ever can be devised—would make it possible to get the energy equivalent of 300 gallons of gasoline from just one gallon of ordinary water. When this happens, man will have achieved the ultimate source of power, able to supply his needs for millions of years. But this development is not just around the corner. Responsible physicists believe it will be another thirty years or more before controlled fusion will be developed to the point where it is the major source of power.

Isotopes for Research and Industry

MORE THAN 100 COMPANIES have been established in the U.S. for the production and processing of radioisotopes for a vast variety of



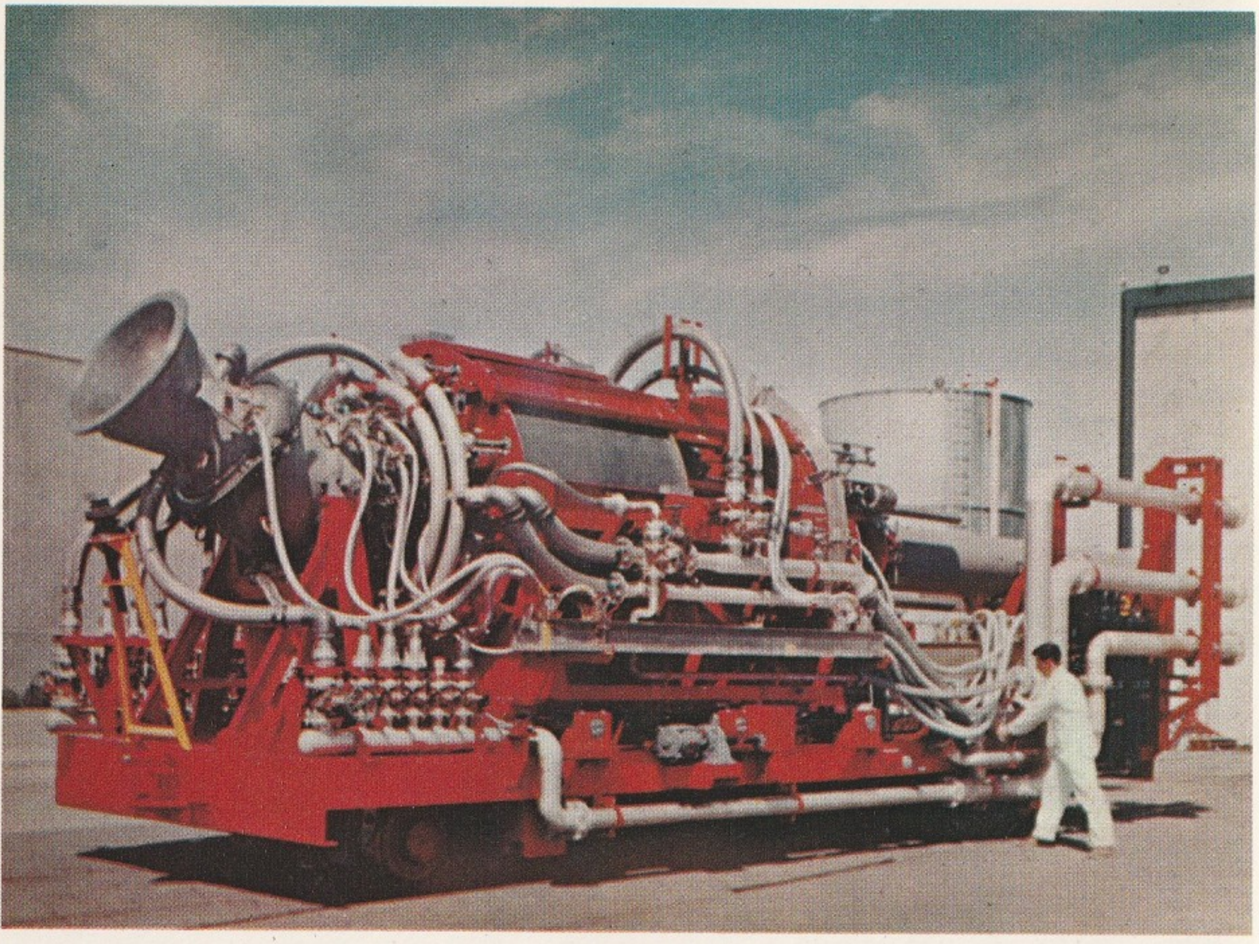
A nuclear power plant supplying 1,000 kilowatts of electricity to this U.S. Air Force Air Defense Command radar station at Sundance, Wyoming, holds the United States record for uninterrupted electrical power generation.

uses. By placing ordinary materials like iodine, gold, cobalt, carbon and many other stable elements in a reactor, neutron bombardment makes them radioactive. Under bombardment they absorb one extra neutron, which makes them heavier than the form that occurs in nature. They get rid of this extra weight by emitting alpha, beta and gamma radiation —they become radioactive. Chemically, they behave exactly the same as the lighter isotopes but they give off energy signals. When withdrawn from the reactor, they can be used for a great variety of purposes.

Gamma-ray emitters like cobalt-60 can be used to X-ray steel. They can vulcanize automobile tires, help speed up the manufacture of certain plastics, or sterilize food without the use of heat. Other radioisotopes are used to study wear of engine parts, to study the flow of substances through the human body and to control the thickness of paper. They can check the efficiency of motor oil, soap or house paint. They can reveal how nutrients are absorbed by plants. Other isotopes may be used to study the efficiency of floor wax and detect leaks in air conditioning systems. Today, in the United States more than 1,500 companies and 250 universities use sixty-five different isotopes for a growing list of jobs. It is estimated that their use is saving many hundreds of millions of dollars for industry alone.

As for commercial applications, the atom is also the father of new products and new industrial processes. By radiating wood that has been chemically treated, manufacturers are producing a plastic wood with all the beauty of natural wood and all the durability of plastic. This product can be permanently painted during the process. The result is something that will last indefinitely, perfect for floors and furniture. Under study is a composition of plastics and solid waste materials such as glass,

Tory 11-A was an experimental atomic reactor in the pioneering United States Project Pluto to demonstrate the feasibility of nuclear ramjet propulsion. This rail-mounted test unit is operated by remote control.



11.

NUCLEAR ROCKET ENGINE

paper and furnace ash by irradiation with cobalt to produce a durable new building material.

Clothing manufacturers are now coating cloth with chemicals, then exposing the material to radiation, giving their clothing permanent creases and better resistance to wrinkles and stains.

Surgical tools and other hospital and industrial goods that require complete sterilization are now being packaged first, then exposed to radiation for foolproof sterilization.

In the chemical industry, many newer plants now use radiation rather than chemicals as catalysts in preparing polyethylene and other products. The nuclear method is cheaper and offers more control of the process.

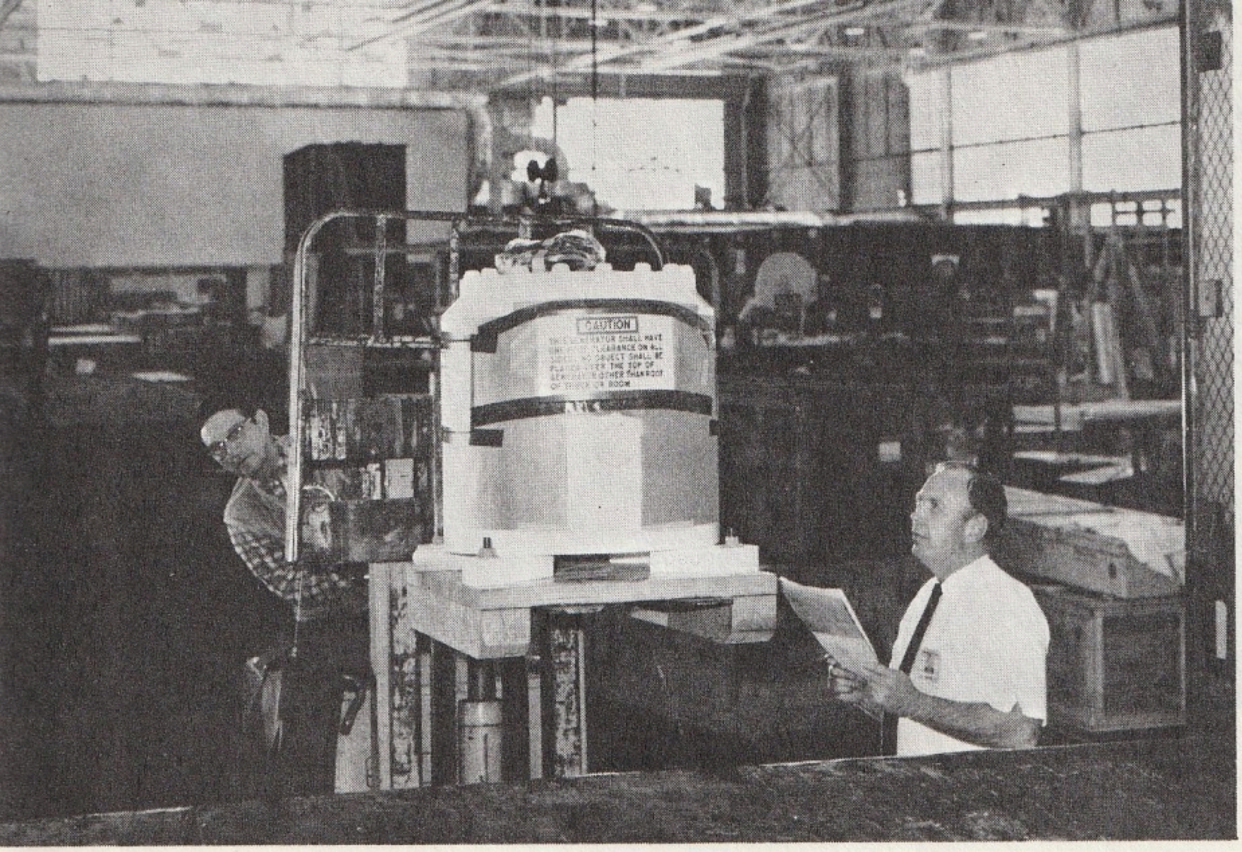
Other Uses for the Atom

MANY TYPES OF REACTORS can be built—great and small, and for many different purposes. What follows are examples of a few of the varied ways the atom is being put to use today:

Medicine. Almost eight million people a year have their illnesses diagnosed and treated by techniques employing nuclear medicine. More than 5,000 medical institutions and 2,500 physicians are licensed to handle radioisotopes. Advances have been made in the treatment of certain types of cancer, brain and heart ailments and diseased organs of the stomach, blood and glands.

To an average patient, nuclear medicine involves the insertion of radioactive material into the body or the use of a radioactive beam directed at parts of the body. In the case of radioisotopes, the material can be picked up and measured after it has been administered. Certain radioisotopes concentrate in certain organs of the body. Because cancerous cells are more porous than normal cells, some radioisotopes also concentrate in cancerous cells quicker than in the surrounding cells. Treatment with isotopes makes use of these individual characteristics. The best success to date has been against hyperthyroidism, a fairly common disease marked by an enlarged thyroid gland at the throat.

A miniature thermionic device which converts heat from a radioisotope directly into electrical power may be used as a cardiac "pacemaker" implanted in heart patients. The tiny battery, about the size of a thimble, can yield about 100 times as much energy as chemical batteries of the same weight. Some medical scientists predict that in time the atom will power "engines" to regulate and eventually to replace the heart. The



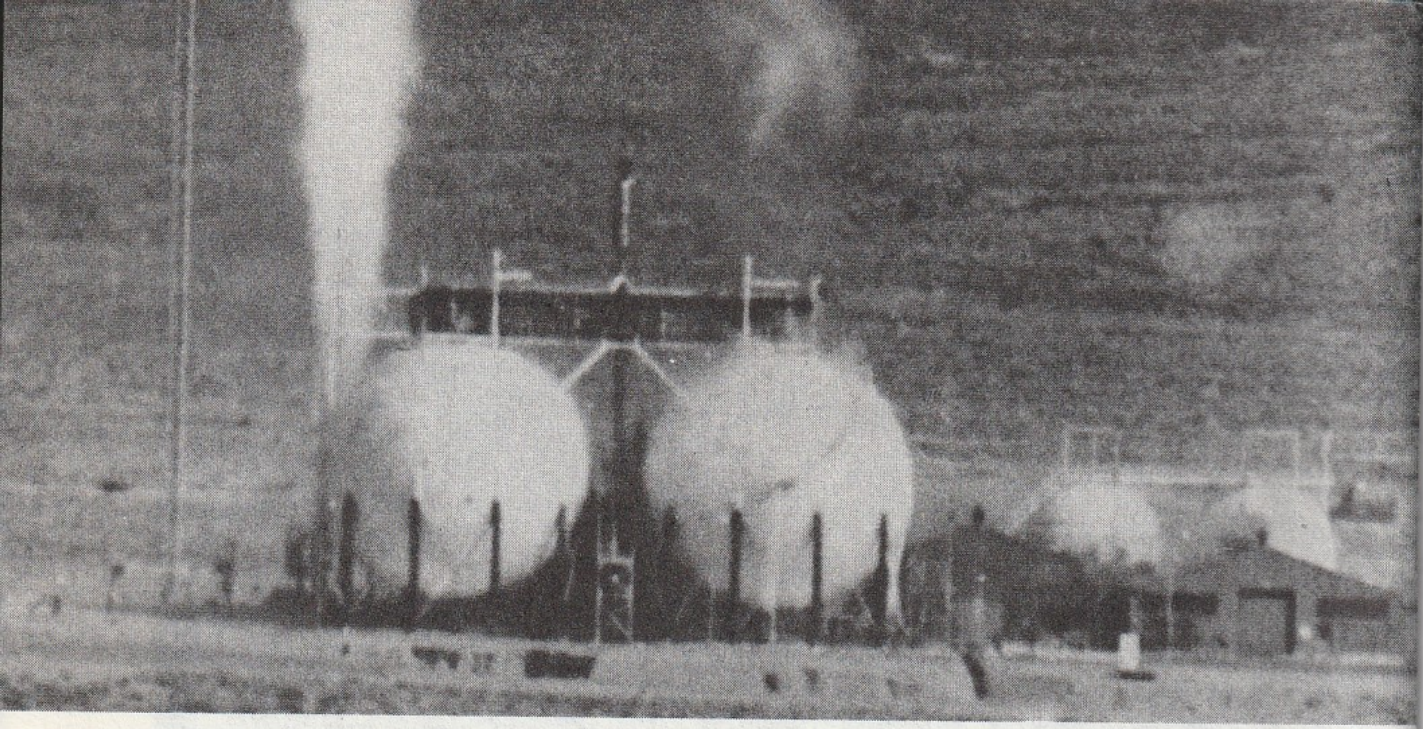
This three-watt nuclear generator is the newest and smallest member of a family of low-cost nuclear generators being commercially marketed for land, water and deep sea use.

A.E.C. has under active study the use of plutonium to fuel a totally implantable artificial heart.

Peaceful explosions. The peaceful use of nuclear explosions is another promising area. Man now has the means—in the atom—for constructing dams and reservoirs, blasting out mountain ranges, or digging sea-level canals. As an earth mover, the atom could cut highway and railway passes through mountains, create harbours and lakes and shift landscapes to improve water and soil conservation.

Earth moving is not the only role nuclear explosions can fill. Some testing has already taken place to construct underground reservoirs for gas and other natural resources, increasing gas well output, controlling subterranean water movement, and extracting minerals from low-grade ores and oil from oil shale. The A.E.C. hopes to perfect tiny "H-bombs" seven inches in diameter for blasting open now inaccessible natural gas reservoirs. These reservoirs, buried thousands of feet in rocks underlying western U.S. states, contain an estimated 317 trillion cubic feet of gas. The idea is to blast a huge chamber thousands of feet deep into which the gas would flow for pumping to the surface.

Ship propulsion. The exploits of nuclear-powered submarines of the U. S. Navy are familiar to all. Soviet Russia and to some extent other nations



A full-power test of an advanced nuclear rocket reactor at Jackass Flats, Nevada.

also are equipping undersea fleets with nuclear power. Other naval vessels use nuclear reactors—from frigates to the largest aircraft carriers. Several nations are experimenting with commercial ships driven by reactor power. Some day there probably will be nuclear-powered submarine oil tankers carrying huge quantities of fuel at high speed—submerged beneath the ocean's surface, free from the discomfort and damage caused by storms.

Reports one authority: "During the next decade we may see nuclear power playing a wider role at sea—in merchant ships, as power sources for navigational aids, ocean buoys, submarine research vessels and undersea laboratories. In addition to that there will be large, fast nuclear freighters and tankers that would require refueling only once in several years."

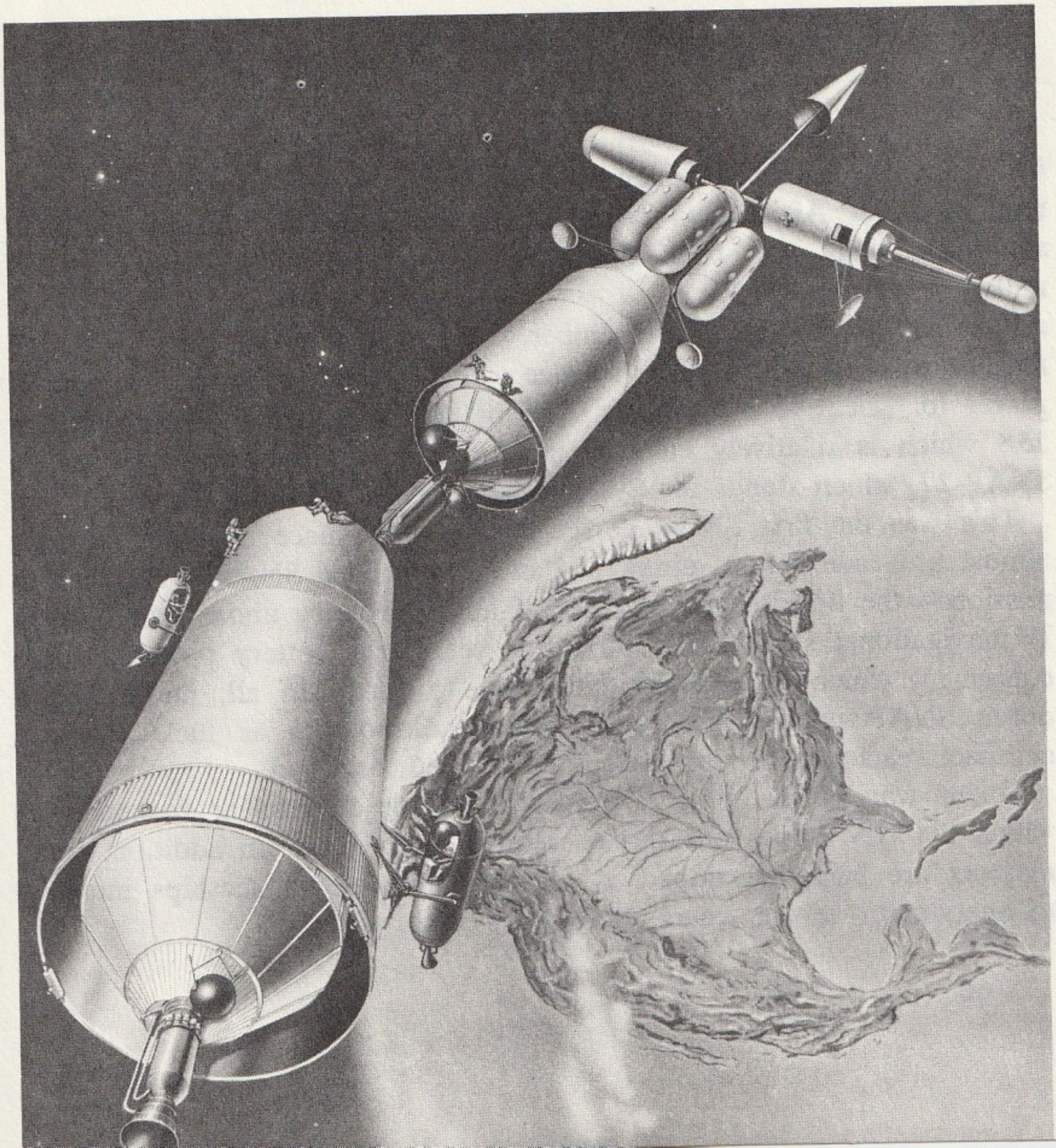
Agriculture. Progress is reported in controlling or eliminating insects, weeds and plant diseases by putting the atom to work on the farm.

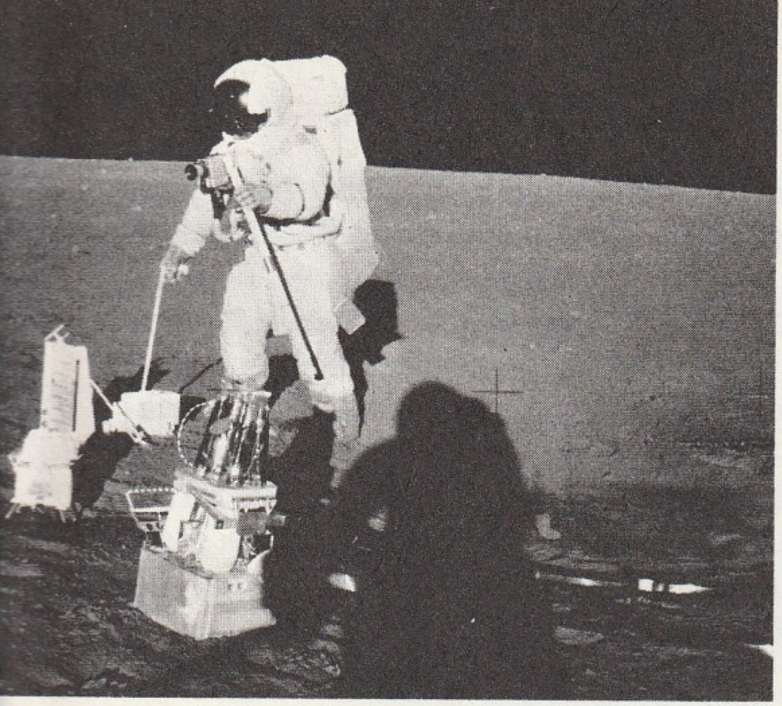
For example, populations of insects can now be eliminated by releasing great numbers of insects sterilized by irradiation into the natural insect population. On the island of Curaçao, this method was used to eliminate the screw worm fly. Success there led to attacks against the sugarcane borer in Puerto Rico, the coffee leaf miner in Central America, and several varieties of fruit flies in Latin America.

The use of irradiation for disinfestation of grain has also been perfected. This is an effective way of destroying insect eggs without harming the grain.

By the year 2000 the population of the earth will total seven billion. Furnishing food for such vast numbers is an agricultural challenge that already has been undertaken. Nearly 100 new plant strains have been developed through mutation by radiation, including a high-yielding rice

A scientists' conception of a nuclear-propelled spacecraft, shown being assembled in an orbit around the earth, as it prepares for takeoff to Mars.





The first "atomic battery" is about to be set up on the moon, on 19 November, 1969. Photo shows an Apollo 12 astronaut preparing to deploy the scientific package that was powered by a SNAP-27 nuclear generator.

in Japan called Reimei, which contains twice the normal amount of protein. And for Africa and India, areas where weather aggravates food shortages, there has been developed a fast-maturing strain of pearl millet.

Atoms in Space. On 19 November, 1969, the crew of the Apollo 12 moonship set up on the lunar surface a small atomic generator to provide power for scientific instruments. The battery was fueled with plutonium 238 which is relatively easy to handle. The moon battery was called SNAP-27, which stands for Systems for Nuclear Auxiliary Power.

This was the first SNAP device carried into space by men. But for almost a decade before, unmanned satellites carried SNAP generators on missions—the first being a five-pound atomic battery aboard the Transit IV navigational satellite in 1961. For years that battery powered radio equipment which transmitted data back to earth. In all, more than a dozen SNAP nuclear generators using radioisotopes as fuel, and one compact reactor generator system, have been launched.

Under way at this time is extensive testing on nuclear rockets with which the U.S. hopes one day to send men to Mars. In addition, small reactors are being developed as power sources for spaceships intended to operate for several years away from earth.

Dr. Glenn T. Seaborg, just before retiring in 1971 as A.E.C. Chairman, predicted: "The seventies will definitely see a melding of the nuclear and space ages as nuclear power becomes a major source of auxiliary and propulsive power for space activities. SNAP units will become a principal source of electricity in space. . . . Eventually, the 1,500-megawatt Nerva nuclear rocket engine will be available for space exploration. Such rocket engines, with 75,000 pounds of thrust, could carry out missions ranging from earth-moon shuttles to heavy-payload missions to other planets."

Looking Ahead

THE FUTURE OF THE ATOM for peaceful uses is bright. The reasons for that are compelling. A cubic inch of uranium metal has the energy potential of 20,000 cubic feet of coal, 30,000 cubic feet of oil, or 25 million cubic feet of natural gas. Since one pound of uranium can do the job of 360,000 gallons of gasoline, atomic fuel may well revolutionize the transport industry. Before the end of the century we will be hearing more about atom-powered dirigibles, atomic locomotives—perhaps even automobiles driven by atomic power.

The atom also carries with it the promise of a new age in which we will have complete control over our environment. With new structural materials from which spotless, airy buildings may be spun, and with the availability of tremendous supplies of heat, power and radioactivity, we may one day build germ-free, air-conditioned cities.

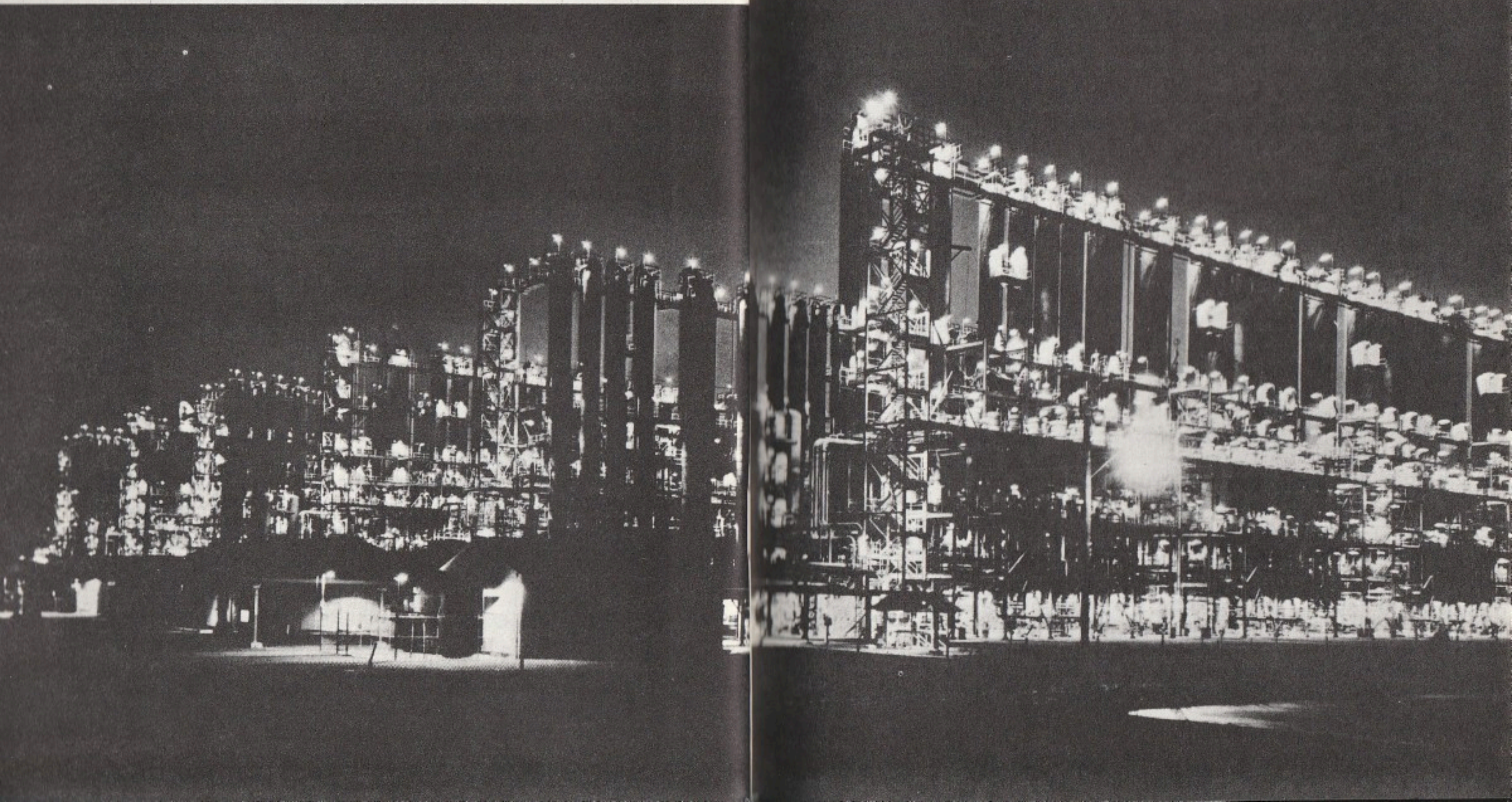
These healthy, contented sheep are on a diet augmented by radioactive foodstuffs. This enables A.E.C. biologists to study absorption and concentration of isotopes in animals' bodies and to increase our knowledge of the safety limits of radiation.

12. RADIOACTIVE FEEDING

Future distillation plants, powered by atomic heat, will produce from the oceans pure, clear water without limit to supply the world's cities and to irrigate arid lands. Mastery of nature's process of photosynthesis will permit the mass production of food by artificial means—enough, perhaps, to feed many times the world's present total population. And if man can achieve what countless scientists are now seeking—the harnessing of the fusion that occurs in the sun and in the hydrogen bomb, we will be provided with limitless energy, enough to last a billion years.

Man's understanding of the atom and its potential has just barely begun. Important new theories are being scouted, and new findings appear each year. Newer and more powerful atom smashers are com-

A striking photograph of the A.E.C.'s Savannah River, Georgia, plant showing the facility for making heavy water, a moderator.



ing into use, and with them will come the discovery of literally dozens of "new" particles.

Because future atomic progress will be based on our understanding of the nucleus of the atom, this research will continue. This is the strange, the wonderful, the exciting, the bewildering, the fascinating world of the atom. We are part of it and it is part of us. Some day we may understand it completely.

Milestones on the Road to Atomic Power

1896	Henri A. Becquerel discovers radioactivity.
1900	Max Planck postulates the quantum.
1905	Albert Einstein develops the quantum theory and the special relativity theory.
1911	Ernest Rutherford describes the nucleus of the atom.
1913	Niels Bohr applies the quantum theory to the hydrogen atom.
1928	The first atom-smashing machine.
1932	First nuclear reaction created by Irene Curie and Frederic Joliot; James Chadwick discovers the neutron; Ernest O. Lawrence invents the cyclotron.
1938	German scientists split the uranium atom's neutrons.
1939	Discovery of atomic fission.
1942	First sustained, controlled nuclear fission chain reaction.
1945	First nuclear explosion; first combat use of nuclear weapons.
1952	First thermonuclear experimental device detonated.
1953	First power reactor placed in operation.
1954	Commissioning of submarine *Nautilus,* marking first application of atomic power.
1956	Start-up of first reactor designed expressly for electric power generation.
1961	First atomic-powered weather station established in the Antarctic. First "atomic battery" placed in orbit aboard Transit IV-A satellite.
1969	First "atomic battery" placed on moon, by Apollo 12.

SCIENCE SERVICE

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